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PB-260 345

WATER QUALITY RECREATION PROJECT. GEIST RESERVOIR INDIANAPOLIS, INDIANA

PUBLIC HEALTH SERVICE
CHICAGO, ILLINOIS

JUNE 1965

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PB 260 345

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COMPREHENSIVE REPORT

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SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-260 345

4. Title and Subtitle Water Quality Recreation Project. Geist Reservoir, Indianapolis, Indiana.

5. Report Date Jun 65

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Public Health Service, Chicago, Ill. Region V.

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

Comprehensive rept

14.

15. Supplementary Notes

16. Abstracts Influence of recreational activity on reservoir water quality is evaluated for the Geist Reservoir in Indiana. The study determines the sources of pollution from the drainage basin and the effect on water quality, available drinking water supply, land development effects, the nature of taste and odor problems resulting from algal blooms, and the effects of agricultural products used on surrounding lands. Physical, chemical, and biological parameters were determined, resulting in a mathematical model that correlates existing factors involved in photosynthesis.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

Geist Reservoir
Indiana
Multiple purpose reservoirs
*Reservoirs
Water quality data
*Recreational facilities
Water pollution
*Pollution monitoring

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 155
	20. Security Class (This Page UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

WATER QUALITY RECREATIONAL PROJECT
GEIST RESERVOIR
INDIANAPOLIS, INDIANA

COMPREHENSIVE REPORT

U. S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
PUBLIC HEALTH SERVICE, REGION V
JUNE 1965

PREFACE

The Indiana Water Quality Recreation Project was initiated in Fiscal Year 1962 to determine the influence that recreational activity has upon reservoir water quality. The initial objectives of the study were to determine:

a. The sources of pollution from the drainage basin and their effect on water quality;

b. the sanitary water quality that is available for a public drinking water supply;

c. the effect upon bacterial quality due to the extensive use of pleasure boats, water skiing, swimming;

d. the effects upon water quality due to the proposed development of lands adjacent to the reservoir for extensive housing;

e. the effects upon water quality of fuel additives, including lead used in the motors of outboard and inboard boats;

f. the nature and potential of taste and odor problems in the public water supply resulting from possible algal blooms;

g. the effects on water quality of the use of fertilizers, pesticides, herbicides and weedicides used on agricultured lands and in the housing area.

Geist Reservoir, owned by the Indianapolis Water Company, a private utility, was selected as the site for the study. It appeared that Geist Reservoir was the only water supply reservoir in Indiana from which it would be possible to accumulate sufficient data concerning physical, chemical and biological factors that would be required to satisfy the study objectives as the housing development progressed and recreational activity increased. During August 1962, Lake Lemon, a reservoir which is one source of water for Bloomington, Indiana, was selected as a second reservoir to be included in the study because unlimited water oriented recreation is permitted. The housing development has not been initiated to date and because of intensified efforts to determine the signifiance of the interrelated parameters affecting water quality changes in Geist Reservoir, Lake Lemon has not been used as a study site.

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ACKNOWLEDGEMENTS

The Indiana Water Quality Recreation Project Staff is indebted to the Division of Sanitary Engineering, Indiana State Board of Health for their assistance and recommendations; to Mr. D. P. Morris, President, Indianapolis Water Company and his staff for permission to study Geist Reservoir and for the use of the laboratory space at the Fall Creek Purification Plant.

Guidance and counseling in planning the project activities and recommendations for changes in program emphasis was generously given by:

H. W. Poston, Regional Program Director, WS & PC, Region V
F. E. DeMartini, Chief, TA & I, SEC
R. Porges, Deputy Chief
W. M. Ingram, Director of Laboratories
E. C. Tsivoglou, Chief, Radiological Pollution Activities
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SUMMARY AND CONCLUSIONS

This study has been in progress through three consecutive recreational seasons. Routine and intensive special sampling and analysis have been conducted in the field and laboratory on selected physical, chemical and biological water quality parameters to attempt to satisfy the project objectives, as stated in the Preface.

The initial approach to the fulfillment of the objectives was to conduct a sanitary survey of the drainage basin to determine the type and magnitude of pollutants entering the reservoir from the tributary streams. Sampling stations were then selected at significant points for continuing routine sample collection to establish base line information. Base line data was necessary in order to correlate future water quality changes.

Statistical analyses were made to determine those parameters which had a significant bearing on water quality changes in Geist Reservoir. Upon completion of evaluation of the data, a sampling schedule was developed. Four of the analyses namely, BOD, total residue, non-filtrable residue and fixed residue, that were conducted during the first sampling season were eliminated.

The final selection of parameters was:

Physical

Water Temperature
Turbidity
Solar Radiation
Wind Velocity
Evaporation
Precipitation

Chemical

Nitrogen
Phosphorus
Alkalinity
Dissolved Oxygen
Specific Conductance
pH

Biological

Aquatic Plants
Benthos
Bacteria

When it became apparent that the proposed housing development at Geist Reservoir would not commence in a reasonable period of time, it was realized that the fulfillment of the objectives pertaining to quality changes caused by increased recreational activity and land runoff from the housing area could not be attained.

At the conclusion of the second year of the program certain trends in the parameters studied were evident. These trends required verification, and in addition, the revised program emphasis dictated that intensive sampling over transects and longitudinal sections of the reservoir should be conducted.

The third year of the study was devoted primarily to the latter approach, with much of the analysis being conducted in the field in order to study in detail the variations which occurred at any given station.

The analyses of the parameters measured in the intensive program led to evaluation of the data which resulted in the development of a mathematical model that correlates the measured factors involved in photosynthesis in this body of water.

The findings and conclusions, summarized below, fall into two broad groups concerning the initial objectives, and ecological studies.

The work of the Project provides detailed information about the initial objectives lettered a, b and f of the Preface. Objectives d and g can be answered in part by applying knowledge gained concerning the use of fertilizers on the surrounding farm land. Objectives c and e have not been investigated. Objective e can be answered in part by applying information obtained by SEC during investigations of outboard motor exhaust pollution.

The sources of municipal wastes, objective a, are shown on the drainage basin map Fig. 41, and are summarized in Table (1).

TABLE (1)

SOURCES OF POLLUTION

Source	Tributary	P. E. before Treatment	Treatment	P. E. after Treatment
Fortville	Flat Fork Creek	2,000	Secondary new plant	300 E
Indiana Reformatory	Fall Creek	3, 300	Secondary being rebuilt	2,500 E
Pendleton	Fall Creek	3,750	Secondary	335
Middletown	Fall Creek	2,000	Secondary	300

The municipalities have liquid wastes that are typical of small towns for there are no large industries. The Reformatory has both a laundry and a small tomato canning plant that discharge to interceptor sewers which discharge to the sewage treatment plant. Sanitary and industrial wastes provide about 10 per cent of the inorganic nitrogen and 70 per cent of the soluble phosphorus that enters the reservoir.

It was found that item b, the quality available for the drinking water supply at the inlet to the reservoir was moderatley hard, with a low BOD, but rich in nutrients. The water leaving the reservoir is of improved mineral quality because of the long detention time which reduces the hardness and alkalinity by about 40 per cent. The natural purification processes also reduce the bacterial count to an average of less than 50 per 100 ml for the greater part of the year. During the high spring flows, the bacterial content is greater.

Objective c, the effect upon bacterial quality due to the extensive use of pleasure boats, water skiing and swimming, could not be fulfilled.

Some information was obtained concerning objective d, the effect upon water quality due to the proposed development of land adjacent to the reservoir for extensive housing. (Table 8 and 15) The reservoir has a high nutrient loading at the present time. Any increase which would result from the housing development would probably cause more taste and odor problems and short filter runs at the purification plant.

The effect upon water quality of fuel additives used in outboard and inboard motors, objective c, was not studied. Data obtained by the Project can be applied to the existing conditions, and then extrapolated to obtain information about the reservoir under heavy recreational use. It was learned that during the 1964 recreational season there were a total of 19,142 boat trips. There was an average of 2 1/2 to 3 people per boat, and each trip lasted an average of five hours. The average fuel consumption was about 1 gallon of gasoline per boat. Most of these trips were confined to the two lower sections of the reservoir which have a total volume of 6.7 billion gallons. A study by English, Surber and McDermott (1) published under the title of "Field Investigation of the Pollution Contribution of Outboard Motor

Exhausts" stated that daily fuel-use rate during the recreational season (mid-May through September) of about 8 gallons per million gallons of water per season, or 0.17 gallons per day per million gallons of water, was required to produce an off-flavor in fish. This information indicates that boating upon Geist Reservoir would have to increase from 10 to 15 times to taint fish.

Objective f, the nature and potential of taste and odor problems in the public water supply resulting from possible algal blooms, is covered in Presentation of Data. Geist Reservoir has a number of taste and odor producing algae, but the Water Company has experienced little difficulty with taste and odor. The heavy nutrient loading will cause extensive problems if the more obnoxious taste and odor producing algae become predominant. The possibility of taste and odor problems developing is of great concern to the Water Company.

Data has been collected concerning objective g. The data provides information on the amount of nutrients that could enter the reservoir, the amount entering the reservoir, and the effect on the reservoir. The eutrophication section provides information concerning the sources of nutrient and discusses their effect on the reservoir.

1. The mineral content of the reservoir water does not exceed the maximum limits suggested in the Public Health Service Drinking Water Standards, 1962.
2. The coliform bacteria counts are less than 50 per 100 ml at the spillway except during the high spring flows.
3. A large increase in recreation could produce a high percent-

age increase in coliform because of the low coliform counts.

4. The ratio of Fecal Coliform to Enterococcus indicates that the bacteria originated in municipal waste.

5. The greatest inflow into the reservoir occurs in March or April each year. In 1964 the period of greatest inflow extended over both months. This period of inflow carried in 80 per cent of the inorganic nitrogen and 71 per cent of the soluble phosphorus.

6. A total of 793,250 pounds of inorganic nitrogen entered the reservoir in 1964. About 10 per cent was contributed by municipal wastes and about 90 per cent was carried in by runoff from farmland.

7. A total of 38,270 pounds of soluble phosphorus entered the reservoir in 1964. About 70 per cent was contributed by municipal wastes and 30 per cent was carried in by runoff from farmland.

8. The nutrient enrichment of Geist Reservoir in 1964 is about equal to the enrichment of the lower Madison Lakes in Wisconsin which have been studied (1942-44) extensively because of their polluted condition.

9. The amount of nitrogen and soluble phosphorus retained in the reservoir during 1964 indicates that the amount of soluble phosphorus added during the year is critical to the production of algae. It has been found that each

increase of one population equivalent (3lbs/yr) of soluble phosphorus that entered Geist Reservoir produced an additional 290-310 pounds (dry weight) of algae per year.

10. The maximum algal growths are limited by the available phosphorus.

11. An algal bloom is a concentration of algae that is readily visible. The definition is ambiguous and unsuitable for Geist Reservoir. Diatom blooms, many times, immediately follow turbidity caused by silt. The diatom bloom could be mistaken for silt.

12. The amount of algae that constituted an algal bloom which effected the water quality of Geist Reservoir was approximately 20 ppm. The average monthly algae mass for 1964 was 23.2 ppm.

13. The amount of phytoplankton produced in 1964 is approximately 4,000,000 pounds (dry weight) per year or more than 2,300 pounds per acre of reservoir surface area.

14. The algal mass varied from 8 pounds per month per acre of reservoir surface to 740 pounds. (dry weight)

15. Algal blooms can occur at any season of the year, except during periods of extremely adverse environmental conditions.

16. Most of the algae found in Geist Reservoir will produce a taste and/or odor during a bloom.

17. Due to the lack of blue green algae produced in Geist

Reservoir, it is concluded that some element essential to their growth is missing. Thus, any pollutants that contain this element could cause a serious algal problem. Identification of this necessary element, which appears to be lacking, for blue green algae in Geist Reservoir could be important in the control of these algae in other bodies of water.

18. During the first half of July 1963 the algae were able to store nitrogen and phosphorus so that photosynthetic activity continued during periods of low nutrient concentration until the end of the month. In August the inorganic nitrogen level dropped to less than 0.20 ppm; the algae were not able to carry on photosynthesis at a rate that could be measured by dissolved oxygen. During the drought of 1963, nitrogen was one of the controlling factors that limited algal production.

19. Transectional and longitudinal studies of the reservoir indicated that turbidity effected productivity for approximately 4,000 feet below station 151. Station 152 was found to be the point of greatest productivity. The portion of the reservoir that has the greatest productivity started approximately one mile above station 152, and extended for approximately one mile below station 152.

20. The minimum amount of light required in Geist Reservoir to produce dissolved oxygen values greater than 100 per

cent saturation was from 1 to 5 per cent of the surface light available when the solar radiation was from 60 to 90 langleys per hour.

21. There is a relationship between depth and algal mass in Geist Reservoir under ecological conditions. In the euphotic zone, the concentration of the algal mass (ppm) increases with depth.

22. The algae that were counted had pigment and unruptured cell walls. Most of the algae below the euphotic zone did not contain pigment or had ruptured cell walls.

23. The depth of the euphotic zone varied from a minimum of 1.5 feet to a maximum of 14 feet. The depth of the zone is influenced by turbidity, the month of the year, the time of day and the amount of sunlight.

24. The greatest dissolved oxygen per cent saturation occurred between 1 to 3 feet. Some of the values approached 300 per cent in the afternoon.

25. A mathematical model or aid was developed using data concerning physical, chemical and biological analyses which shows the relationship between these factors and photosynthetic activity.

26. The analyses for BOD and residues were found to be influenced by the algal mass. These results were, therefore, of little value for interpretion.

27. In 1964, the greatest number of benthic organisms were

found in section I just below station 152. Sections II and III should have the greatest number of benthos because of the nutrient loading, the shallow depths and large surface area. It appears that high turbidity and fluctuations in water level have reduced the number of benthic organisms in the upper portion of the reservoir.

28. Turbidity, precipitated solids and aquatic plants have reduced the storage capacity of the reservoir.

29. Turbidity has limited the number of large aquatic plants.

30. The reservoir is not in "fish balance." Some types of forage fish have become stunted. Turbidity has limited the production of predatory fish. More predatory fish are needed in Geist Reservoir to maintain a proper fish balance.

31. In March 1965 water samples were collected to determine if pesticides were present. The GLIRBP laboratory analyzed these samples by a method general enough to include most types of pesticides. All samples had negative results.

32. Over 500,000 hours and $386,000 are spent per year in order to catch fish at Geist Reservoir.

Chronicle:

During Fiscal Year 1962, the Public Health Service initiated the task of developing a plan of a study to take place in Indiana to determine the influence of recreational activities upon water quality. In addition to the study concerning recreational activity, the program was to include the influence of other pollutants upon water quality. The first step was the establishment of a sound working relationship between the Indiana State Board of Health, the Indianapolis Water Company and the Public Health Service.

A sanitary survey of the watershed was conducted, following which sampling was initiated in May 1962. The Project staff shared the laboratory facilities of the White River Purification Plant until December 1962.

During January 1963 the laboratory equipment was transferred to an unused laboratory in the Fall Creek Purification Plant. This laboratory was equipped with only about 16 feet of laboratory bench space and a still for water. Project personnel obtained unused temporary laboratory tables from GLIRBP, transported them to Indianapolis, and installed them in the Fall Creek laboratory.

The intensive sampling season of 1963 extended from mid-April to mid-October. The work concentrated upon the collection and analyses of samples from several routine sampling stations. Since a broad background of base line data was desired for statistical analyses, samples were collected several times each week and analyzed for chemical, bacteriological, and biological content. In addition to the routine work, nine sets of samples were collected for the Virology Unit at SEC. Four sets of samples were collected and shipped to the GLIRBP laboratory for gross mineral analyses.

A Review and Planning Conference held at SEC in December 1963, resulted in a suggestion that the study emphasis be shifted to the investigation of the influence of nutrients upon algal activity which affects water quality. The shift in emphasis was approved at the Annual Program Review during February 1964.

The intensive sampling season of 1964 extended from the first week of May through the third week of October. Weekly routine sampling was conducted, followed by investigative studies. Continuation of the collection of information by routine sampling provided for correlation of 1962 and 1963 data with the quality changes that occurred during 1964, and also provided information that acted as a base line used in evaluating the results of the investigative studies. These studies investigated the quality changes within the reservoir in an effort to determine the magnitude of the variations in quality and the cause of the variations.

The Annual Program Review held in Chicago in February 1965 resulted in a revision of future operations. The anticipated study of Lake Lemon in fiscal year 1966, was cancelled. Project personnel were instructed to prepare a comprehensive, interpretive report to be submitted in June 1965, which would serve as a basis for determination of future project operations.

Geist Reservoir and Drainage Basin:

Geist Reservoir, Fig. 42, is located about 15 miles northeast of Indianapolis, Indiana and is owned by the Indianapolis Water Company an investor owned utility. The reservoir is 7.5 miles long, has a surface area of 1,800 acres and a shoreline of 35 miles. Its storage capacity is 6.9 billion gallons.

The reservoir is divided into three unequal basins by two causeways. The upper portion, section III, is the smallest and the shallowest with a capacity of 0.20 billion gallons. It is primarily a silting basin.

The middle portion, section II, could be classified as a super pond. The average depth is about 10 feet with a maximum depth approaching 15 feet and a capacity of about 1.1 billion gallons.

The lower section, section I, could be described as a Eutrophic Lake. It has a capacity of approximately 5.6 billion gallons, an average depth of about 20 feet and a maximum depth of 30 feet.

The watershed above the dam is 215 square miles in area, Fig. 41. The land is gently rolling to flat Wisconsin Glacial Drift which is used primarily for farming. There are roughly 950 farms with a total acreage of about 137,000 acres. The most important crops are corn, wheat, soybeans, hay, and pasture. Fertilizer is utilized to increase the productivity of the farms. A few head of cattle, hogs and sheep are usually raised on each farm so that the number becomes impressive when the total live stock population is considered.

Sampling Stations:

Routine sampling of the reservoir was conducted from bridges. The sampling points are shown on the appended map, Fig. 42, and are numbered 111, 112, 113, 151, 152, 191 and 192. The inflow stations are in the 110 series. The reservoir stations are in the 150 series and the outflow stations are in the 190 series.

Station 111 is located on Fall Creek on a county road bridge just below the small settlement of Lux Haven. Samples were taken at mid-depth at the first quarter point from the north end of the bridge. This location was selected for it is at the point of maximum flow and is 1,000 feet upstream from Geist Reservoir. Fall Creek supplies most of the water to the reservoir, and is gauged at a bridge about one mile upstream from station 111.

Stations 112 and 113 are located on small wet weather tributaries. In both cases, the sample is collected at mid-depth and at mid-span of a bridge crossing.

Stations 151 and 152 are located at mid-span on the upstream side of the respective bridges. Sampling depth was five feet.

Station 191 is located on the upstream side of the dam near the outflow trash rack. Sampling depth was five feet. Station 192 is located on the first bridge downstream from the dam and is the uppermost sampling point of the water company. Station 192 was selected to aid in correlating project reservoir water quality data with water company data.

The locations of the sampling stations for investigative studies are shown on the map of Geist Reservoir, Fig. 42. The longitudinal sampling stations are marked with a ⊙ , while the stations used in a transect are marked with an x.

Method of Study:

During the first intensive sampling season, 1962, samples were usually collected on Tuesday, Friday and Sunday from the routine stations. These days were selected because it was felt that with an increase in recreational activity the quality changes produced by recreation would be more pronounced on Sunday and not as great on Friday. The intensive sampling season of 1963 indicated that the Friday-Sunday theory is of little value because the quality changes vary with climatic and nutrient conditions.

During the first season, analyses run on each sample included specific conductance, total and orthophosphate, ammonia, nitrite and nitrate nitrogen, temperature, dissolved oxygen, BOD, chloride, total alkalinity, total hardness, non-filterable residue, fixed non-filterable residue, loss on ignition to 600° C. and coliform. Color was run at the beginning and close of the season. The results of the color determinations were fairly uniform for all stations for both periods.

The sampling carried out in 1963 utilized the stations established in 1962. The data collected during the 1963 intensive sampling season provided a continuous record of the changes in the reservoir at the routine reservoir stations from April to October. Samples were analyzed for temperature, pH, alkalinity, D. O., specific conductance, turbidity, nitrate, nitrite and ammonia, total and orthophosphate, total and fecal coliform, enterococcus and phytoplankton.

The routine sampling of the 1964 intensive sampling season followed the pattern of 1963. Investigative study sampling was initiated during the last of May with temperature and dissolved oxygen studies carried out from a boat. The D. O. determinations could be done rapidly at any depth for they were made with a galvanic cell oxygen analyzer, which was equipped with a thermister thermometer so that temperature and D. O. measurements were taken simultaneously at the same depths.

Light penetration measurements were added to the studies in June after a submarine photometer was received. In June the use of the oxygen analyzer was discontinued because the algae in the reservoir were producing more oxygen than the equipment could measure. The instrument was modified by installing components supplied by the manufacturer to extend its range.

In July a physical science aid was added to the staff, a portable specific conductivity meter that had been on order for 6 months was received, and a raft was constructed so that laboratory bench space could be made available near each sampling point. Measurements and analyses were made simultaneously with equipment and other facilities available and were carried out on the raft and in the boat in the following manner:

1. Work from the boat included:
    a. Temperature, taken at the surface and 2 1/2 ft. increments to 10 feet, then 5 foot increments to the bottom.
    b. Dissolved oxygen, surface to bottom at the same depths.
    c. Specific conductance, surface to bottom at

the same depths.

d. Light, surface to bottom in one foot increments.

e. Samples from the surface plus 2 1/2 ft. and 5 ft. increments were taken to the raft.

2. The analyses and other work carried out on the raft were:

   a. pH
   b. Alkalinity
   c. Hardness
   d. Turbidity
   e. Preservation for the nitrogen and phosphorus
   f. Preservation of algal samples

The nitrogen cycle (ammonia, nitrite and nitrate) and phosphate (ortho and total) analyses were carried out in the laboratory the next day.

PRESENTATION OF DATA

Biochemical Oxygen Demand:

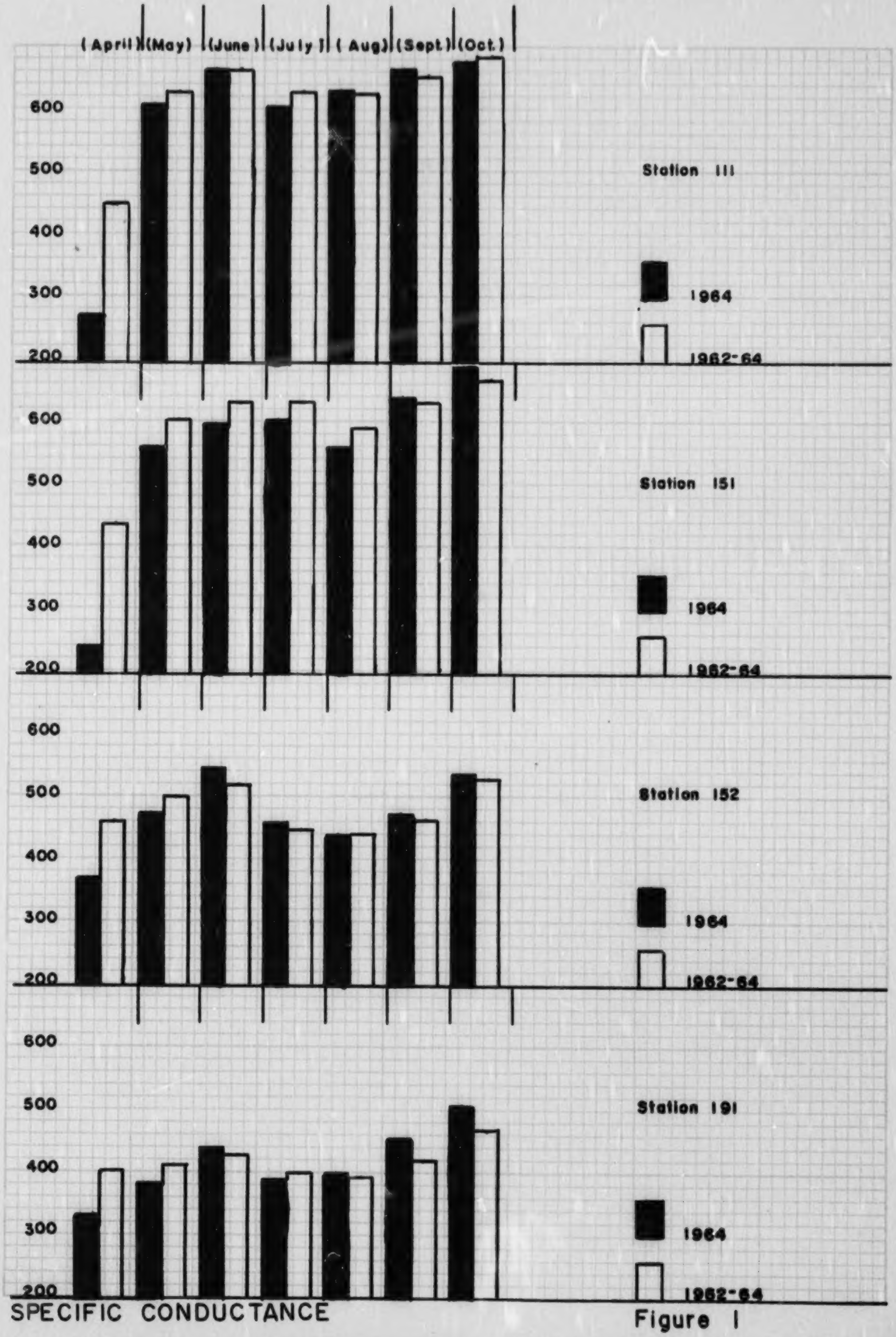
The test for biochemical oxygen demand was conducted during the 1962 sampling season. The average results are: station 111, 2.3 ppm, station 151, 4.9 ppm, station 152, 4.7 ppm, station 191, 3.0 ppm. Neel et al (1961) (2a) indicates that the biochemical oxygen demand measurements of algal laden water are difficult to evaluate. Some of the available oxygen in the BOD test is used in the metabolism of the algae. The greatest values in BOD occurred at stations 151, 152 and 191 where the algal mass was the greatest, and it is believed that phytoplankton influenced the BOD results. The analysis for BOD was discontinued following the 1962 season, because an evaluation of the data indicated that BOD results were of little value in explaining ecological variations.

Residue:

In 1962 the analyses for residues were conducted routinely. A reduction of 45 per cent occurred from the inlet to the outlet of the reservoir. An evaluation of the 1962 data indicated that the amount of residue was influenced by the amount of algae present. The analyses for residues were discontinued in favor of other analyses that could be evaluated more accurately.

Specific Conductance:

Specific conductance is an estimate of the total concentration of the ionized substances in a sample of water at a given temperature



SPECIFIC CONDUCTANCE

Figure 1

that can be measured by the water's capacity to convey an electric current. The measurements are reported as micromhos per centimeter at 25 degrees centigrade. Table (2) shows the average specific conductance for each year at each station.

TABLE (2)

SPECIFIC CONDUCTIVITY

	SAMPLING STATIONS				% loss
Year	111	151	152	191	111 to 191
1962	640	615	480	395	38.3
1963	655	595	490	425	35.2
1964	585	550	475	430	26.5

Swindale and Curtis (1957) (3a) made a study of submerged aquatic plants and calculated indices for the occurrence of species within a measured area. They compared these indices with the ecological factors and found a correlation with specific conductance.

A "rule of thumb" statement can be made that the higher the index number, the higher the specific conductance value, and usually the larger the stature and/or the bulk of the plant. Geist Reservoir water has a high specific conductance value and the aquatic plants are large in stature.

pH:

"pH is the logarithm of the reciprocal of the hydrogen ion concentration--more precisely, of the hydrogen activity--in moles per liter." (4a)

Neel et al (1961) (2b) states that in Stabilization Ponds (sewage lagoons) studied, a pH value above 8.0 is the result of photosynthesis. The pH of water in Geist Reservoir does not follow the photosynthetic trend, that increasing pH indicates photosynthesis. No trend could be developed by graphing monthly averages of pH and dissolved oxygen. The yearly pH values indicate that the greatest photosynthetic rate occurred in sections I and II of the reservoir. These yearly pH values are shown in Table (3).

TABLE (3)

pH

	STATIONS			
Year	111	151	152	191
1962	8.03	8.26	8.31	8.24
1963	8.01	8.19	8.30	8.35
1964	7.99	8.00	8.16	8.18

Dissolved Oxygen:

Dissolved oxygen is added to water by absorption or by photosynthesis. The important source of oxygen for lakes and reservoirs is the aquatic plants. Plants with chorophyll utilize carbon dioxide in the presence of solar energy and produce oxygen as a by-product.

Geist Reservoir's greatest per cent saturation usually occurs between 1.5 to 3.0 feet of depth. The fact that the greatest values for dissolved oxygen were found between 1.5 to 3 feet is not a true indication of the productivity of the algae at a given depth, because oxygen as well as other gases will pass up through the water until they are dissolved or pass into the atmosphere.

The afternoon dissolved oxygen values were usually greater than 100 per cent saturated in the euphotic zone during late Spring, Summer and early Fall of 1964. During 1963, from April to August the afternoon dissolved oxygen was greater than 100 per cent saturated. In August 1963, a drought started and continued into 1964. Dissolved oxygen values were usually less than 100 per cent saturated during this period, because of the reduction in nutrients.

Section III acts as a shallow silting basin. When the Reservoir is full, the average depth of this area is less than 3 feet. The dissolved oxygen in this section was super saturated when the turbidity was less than 200 units.

Section II has a greater algal productivity than section I, because it is shallow and is closer to the influent of Fall Creek with Geist Reservoir. The greatest fluctuations occurred in this section. There was as little as 50 per cent to as much as 270 per cent dissolved oxygen in a 48 hour period.

Based on the transectional and longitudinal samples from May to August 1964, the dissolved oxygen concentration in section I varied from 242 per cent of saturation, near the surface to 10 per cent in the bottom water. The euphotic zone was approximately 10 feet deep and the layer of bottom water, which had less than 10 per cent saturation, varied from 2 to 10 feet depending on the total depth of the water.

Photosynthetic activity occurred during May to August. The pH varied from 8.35 to 8.70 and the total alkalinity from 118 ppm to 134 ppm in the euphotic zone. At the 25 foot depth, the pH was between 7.40 to 7.50.

The effect of photosynthesis from August to October, 1964, in section I was not as great as in the spring and early summer period. The dissolved oxygen varied from approximately 180 per cent saturated near the surface to less than 10 per cent at the bottom of the reservoir. The euphotic zone was between 15 to 25 per cent less in depth and the dissolved oxygen was not super saturated until an hour later in the day. (See Figs. 3, 4 and 5)

Welch (1952) (5a) states there are two kinds of currents, "horizontal" and "returning or undertow", that can be attributed to wind velocity in lakes or reservoirs smaller than the Great Lakes. The effect of these currents is dependent upon the velocity and duration of the wind.

An "undertow" current was developed in Geist Reservoir when the wind reached a velocity greater than 10 miles an hour for a period of over 24 hours. Six samples taken from 1962 to 1965 at sampling station 191 appeared to be affected by an "undertow." The analyses of these six samples appeared to be a mixture of bottom water and water usually found in the euphotic zone. These samples were taken after a period, longer than 36 hours, during which the average wind velocity was greater than 10 miles per hour.

Since dissolved oxygen is a by-product of phytosynthetic action,

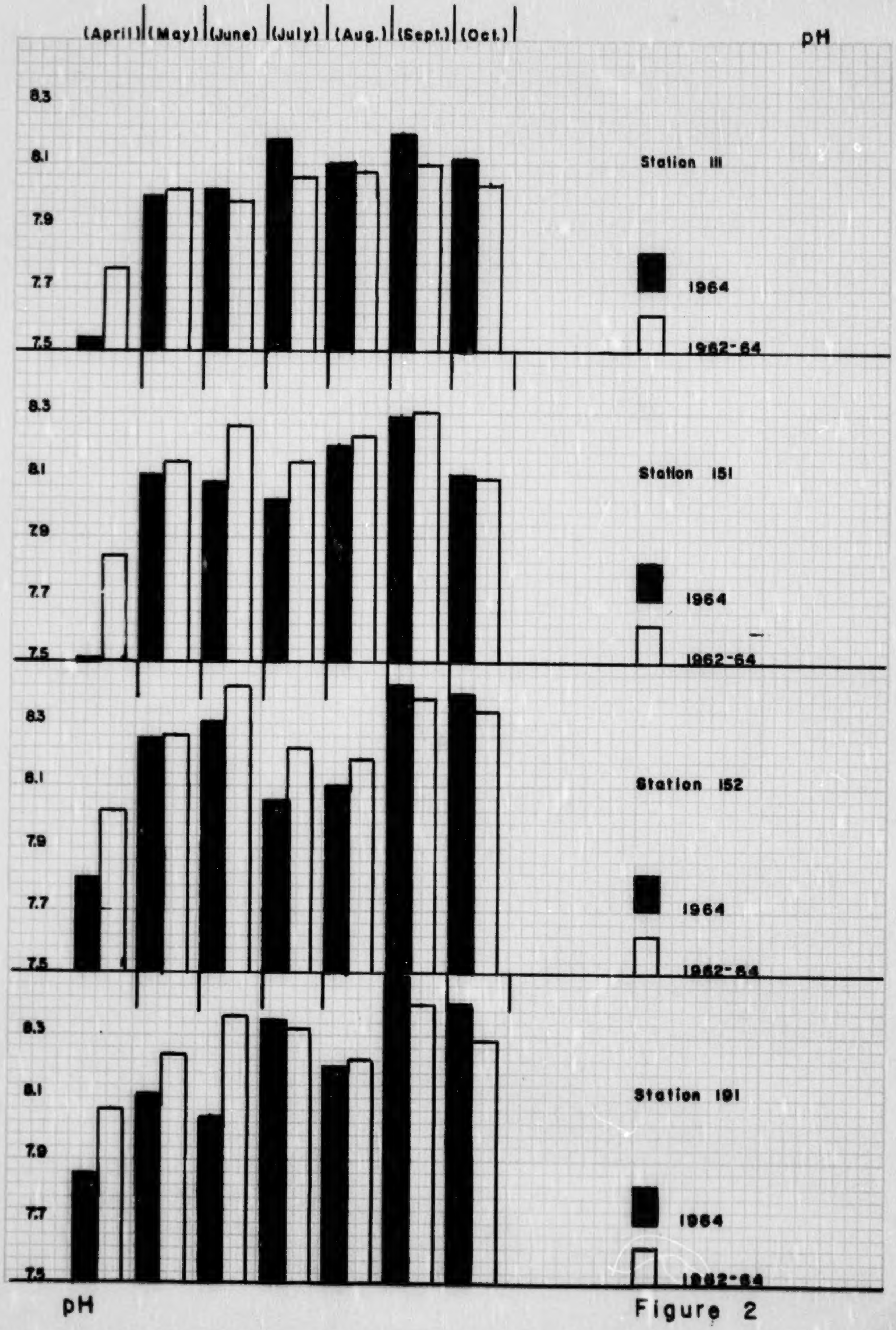
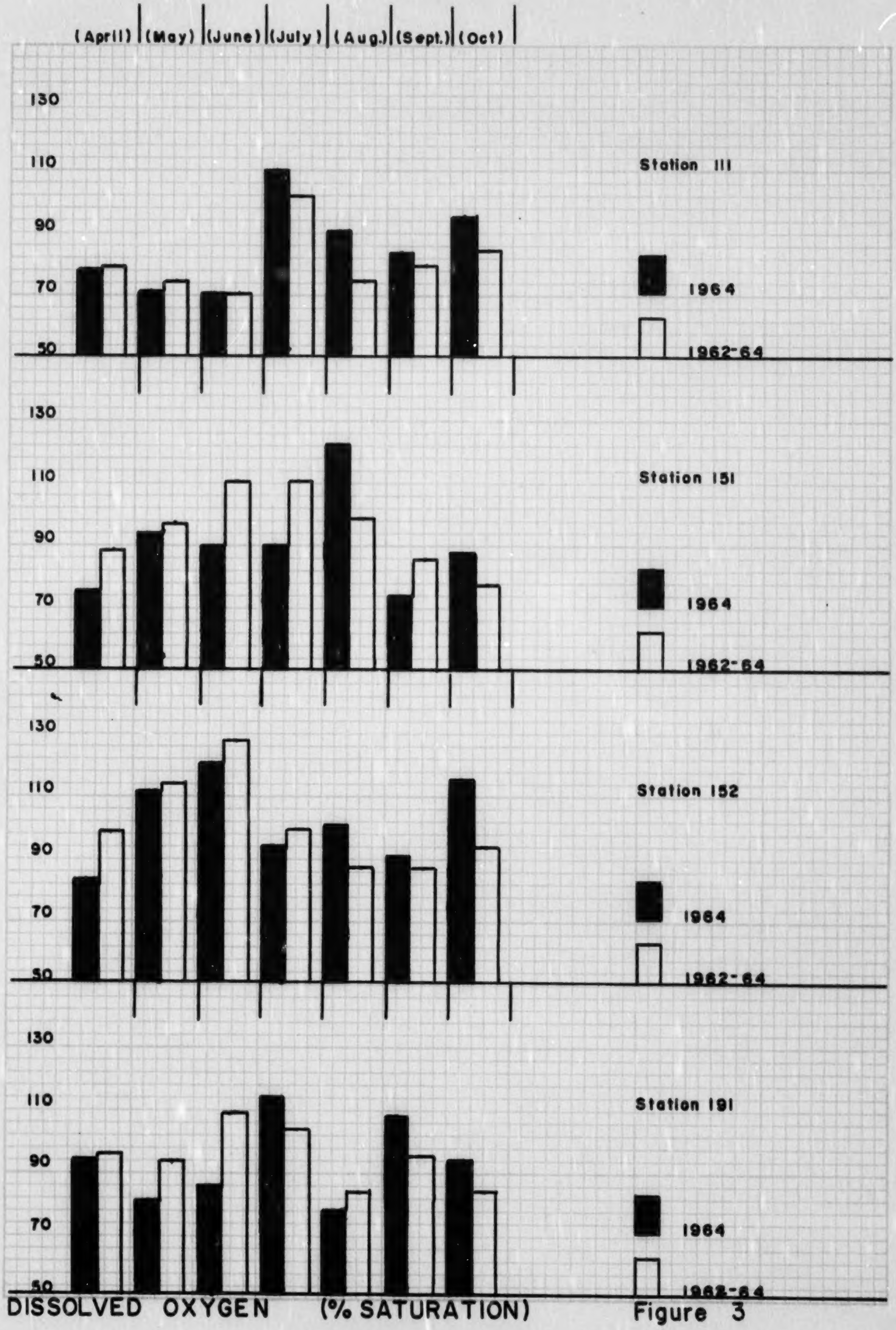

(April)
(May)
(June)
(July)
(Aug.)
(Sept.)
(Oct.)
pH
8.3
8.1
7.9
7.7
7.5
Station 111
1964
1962-64
Station 151
1964
1962-64
Station 152
1964
1962-64
Station 191
1964
1962-64
pH

Figure 2



DISSOLVED OXYGEN (% SATURATION) Figure 3

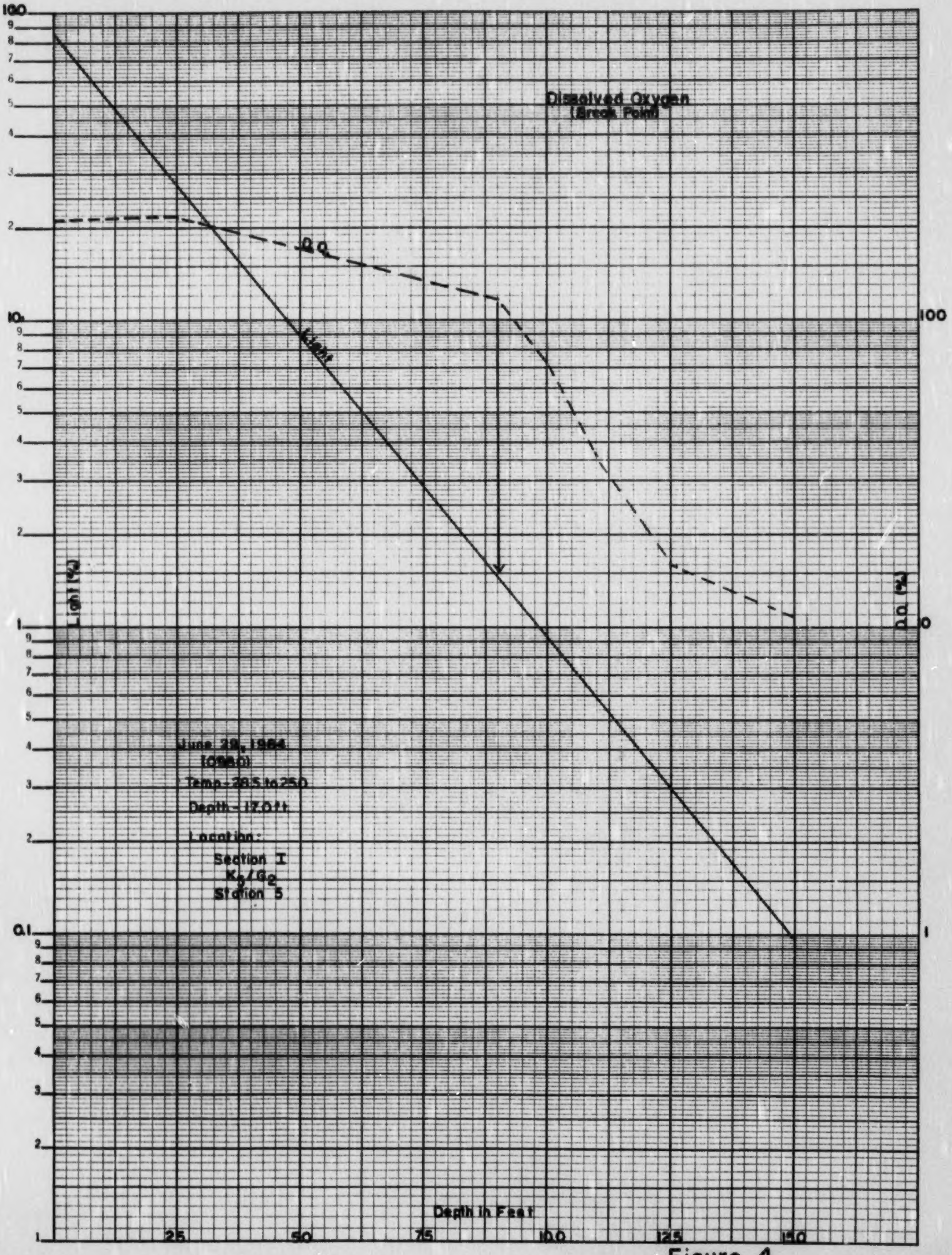


Figure 4

K+E SEMI-LOGARITHMIC 46 6013
CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO

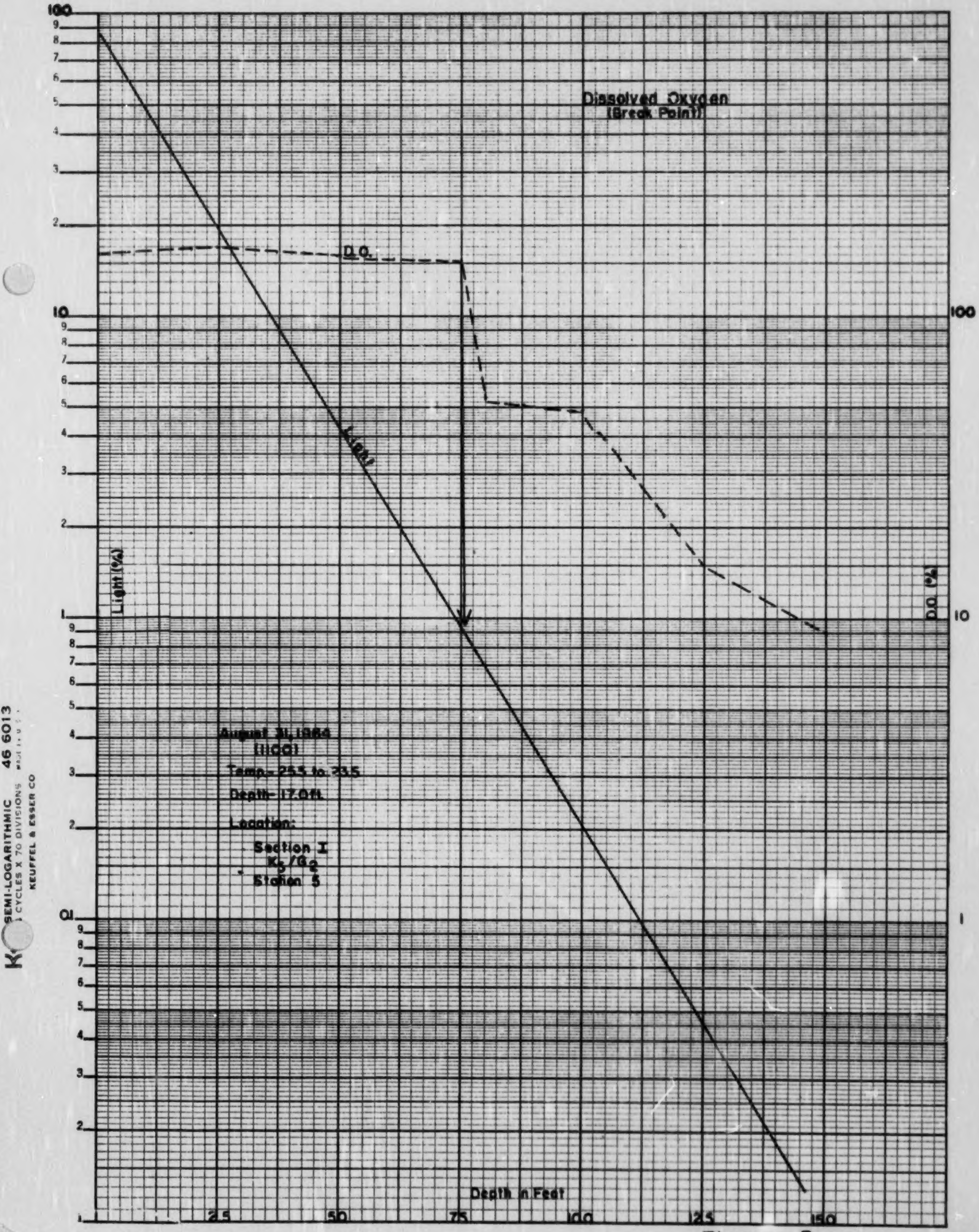

Dissolved Oxygen
(Break Point)
D.O.
Light
Light (%)
D.O. (%)
August 31, 1964
(1100)
Temp.- 25.5 to 23.5
Depth- 17.0 ft.
Location:
Section I
K5/G2
Station 5
Depth in Feet
25
50
75
100
125
150
100
10
1
0.1
SEMI-LOGARITHMIC
3 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6013

Figure 5

observations of the analyses made it possible to develop a mathematical model relating the ecological factors studied in Geist Reservoir. A detailed discussion of the development of the model is given in Appendix A.

Solar Radiation:

The depth that light can penetrate water is determined by the transparency of the water, time of day, latitude of the place, and the month of the year. In Geist Reservoir, during open water and with turbidity less than 15 units, the greatest depth of the euphotic zone was approximately 14 feet. The euphotic zone was reduced to a depth of less than 18 inches, during the periods of great inflow because of turbidity.

Solar radiation data was supplied by the U. S. Weather Bureau station in Indianapolis. Normally, solar radiation measurements are made in langleys per day. Calculations were made using the weather bureau data and the depth of the euphotic zone to determine the amount of light the reservoir received prior to sampling and also the intensity of light at any given depth. Figs. 6 and 7. These measurements are approximate calculations, but they are the best that can be made with the available data. The project now has a pyroheliometer so that hourly and daily solar radiation levels can be measured. This equipment will accurately measure the total amount of solar energy and the amount available to aquatic plants at any depth on a given day in Geist Reservoir.

The problems of light measurements "In Situ" are recognized by

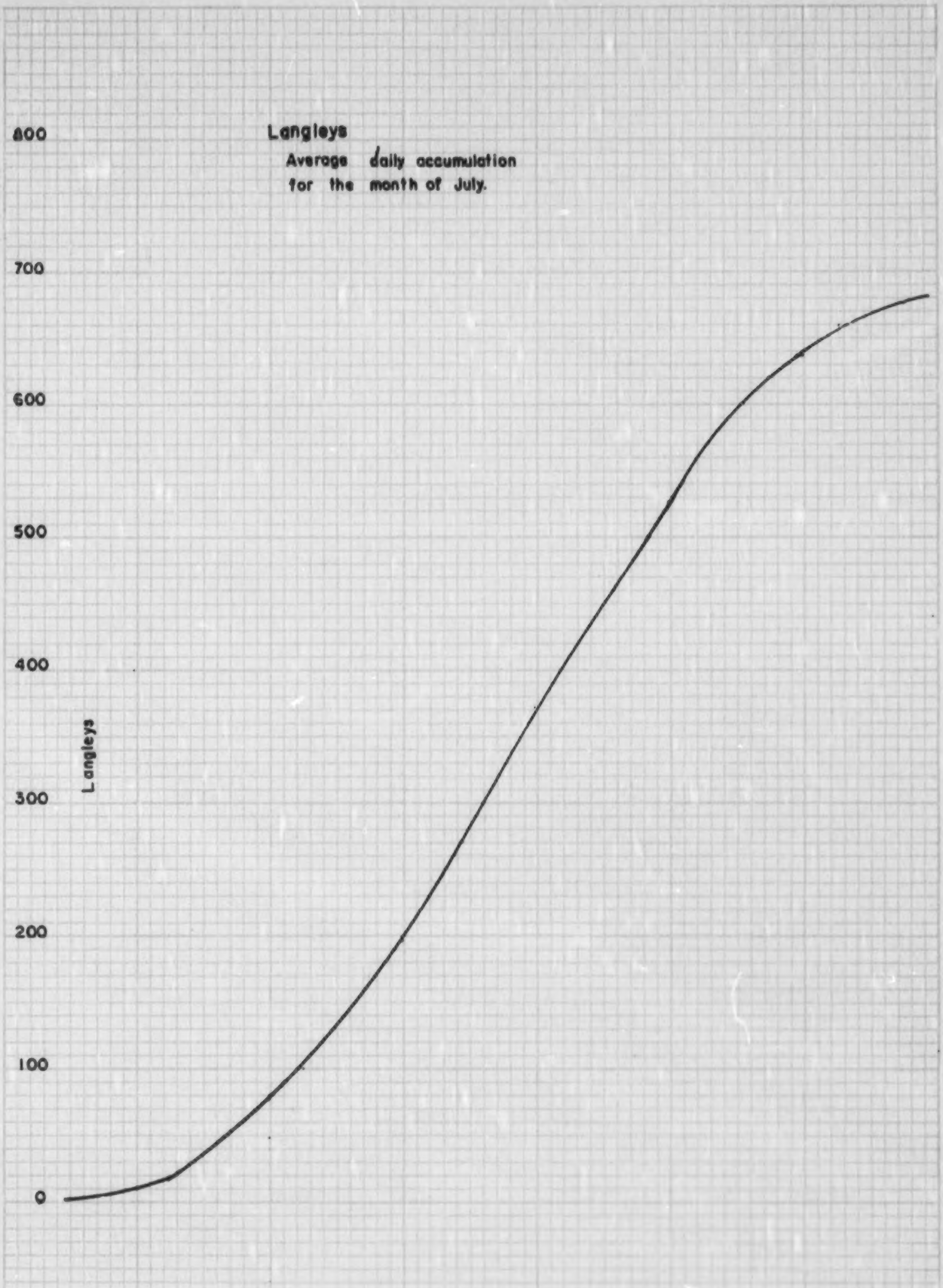

Langleys
Average daily accumulation
for the month of July.
800
700
600
500
400
300
200
100
0
Langleys
Time
0700
0900
1100
1300
1500
1700

Figure 6

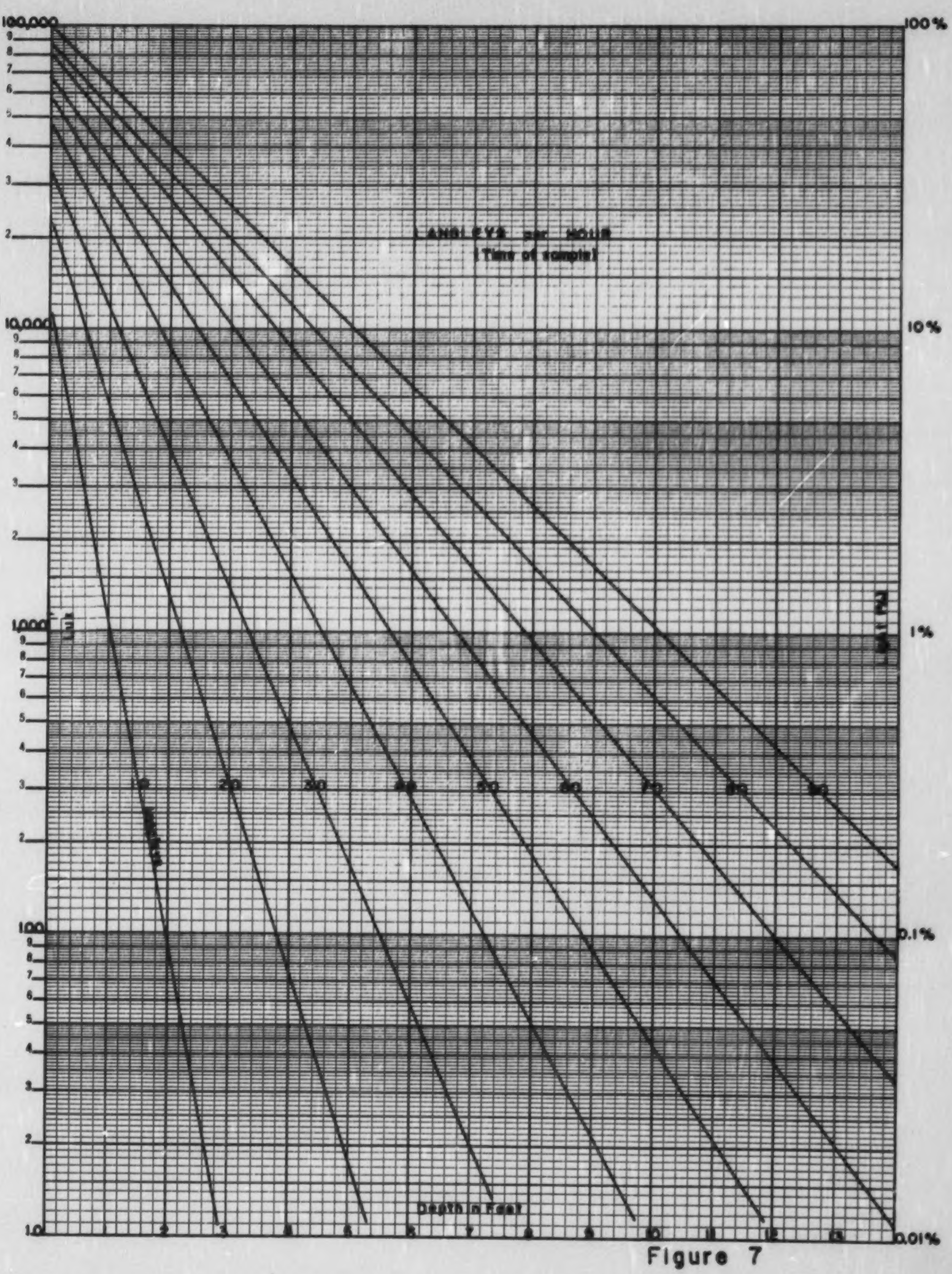


Figure 7

K+E SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

investigators who study aquatic life. (6) Standards have not been developed that are acceptable for different types of environment and different organisms. Each genera of aquatic plants probably has a preference for a given light wave or for a given intensity of light. Welch (1952) (5b) states Shelford's law of toleration as "A factor exercises a controlling influence upon production according as it is near the optimum or near either the maximum or minimum tolerated by the species." The stigma found in zoospores and some flagellates is a light-sensitive spot that is suspected of causing the organism to be attracted or repelled by light. With blooms of Euglena this sensitivity to light can cause variations in algal concentrations which are difficult to correlate with dissolved oxygen or other parameters.

The greatest per cent saturation of dissolved oxygen in Geist Reservoir occured at approximately 2.5 feet depth. When the sun was at its zenith on a cloudless day, the light intensity would range between 10,000 and 50,000 lux, at 5 feet if the euphotic zone was 10 feet. The literature is confusing on the amount of light that will give the greatest gross algal production. The optimum amount of light intensity for photosynthesis has been reported as ranging from 380 (7) to 55,000 (8) lux for different types of aquatic organisms. Maddux and Jones (1964) (9) found in laboratory experiments with sea water that the optimum light intensity was influenced by the water temperature and the amount of nutrients present.

Water Temperature:

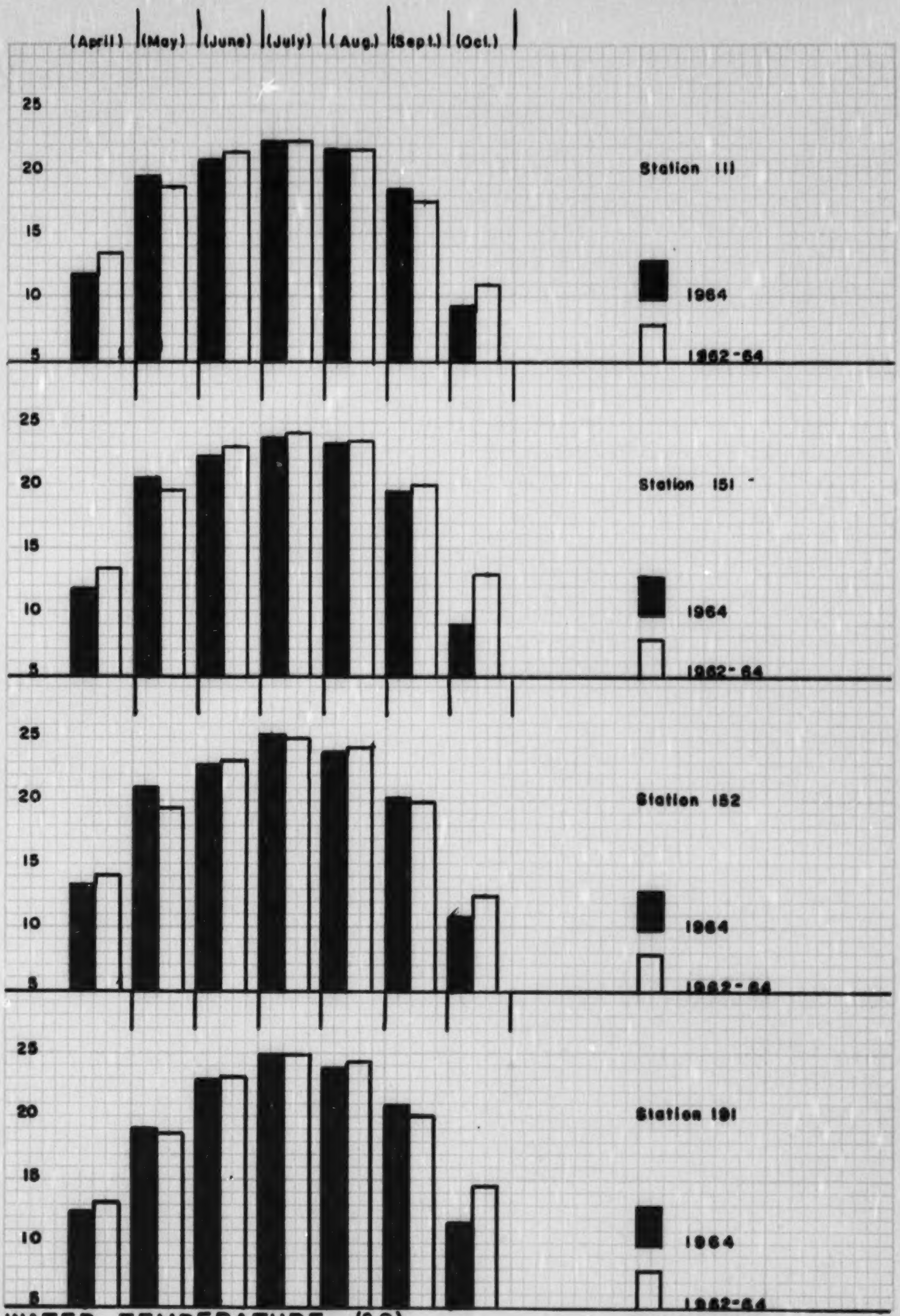
Water temperature in a reservoir is influenced by five major factors; air temperature, wind action, solar radiation, turbidity or colored matter that can absorb solar heat, and inflow to the reservoir. There are other factors that can influence water temperature that may be of major importance. One example occurs in Lake Vanda in the antarctic where the bottom of the lake is heated by conduction. Ragotzkie and Liken (10) states that this lake has five layers of stratified water but has an inverted temperature structure which is hydrostatically stable because of the difference in salt concentration.

Since Geist Reservoir is a shallow reservoir with a maximum depth of thirty feet and a mean depth of approximately seventeen feet, a thermocline does not develop. If a thermo-stratification did occur it was only for a limited time and was not found during the sampling periods.

All temperatures taken in depth were recorded in degrees centigrade with thermistor thermometers which were periodically calibrated against a certified precision laboratory thermometer. The greatest variation from the surface to the bottom of the reservoir was seven degrees. The average variation was five degrees. The thermo variation in the euphotic zone was not more then three degrees.

During the period of partical ice cover, the water temperature at the surface fluctuated between 0° C. and 6° C. When total ice cover occurred, the surface water was 0° C. and gradually increased to 4° C. near the bottom of the reservoir.

The temperature varied from 10° C. to a maximum of 26° C. from



WATER TEMPERATURE (°C)

Figure 8

April 1 to November 1. Maximum temperatures occurred during the last half of July and first half of August.

The greatest quantity of phytoplankton were found when the temperature spread was between 16° C. and 22° C. Maddux and Jones (1964) (9) in their work with Nitzschia closterium, a marine diatom, cultured in an artificial sea media, found that there is a relationship between temperature, nutrient, and solar energy. They investigated two extremes of nitrogen, from 10.0 mg/l maximum to 8.9 ug/l minimum of N; the nitrogen to phosphorus remained constant at a 19:1 ratio. With the larger amount of nutrients, the greatest productivity occurred at 22.5° C., the next was 16° C., the third was at 31° C., and then 10° C. When 8.9 ug/l of nitrogen was used, the highest productivity occurred at 16° C., the second at 10° C., the third 17.5° C., the fourth at 22.5° C. and least at 31° C.

It is apparent that temperature can increase or decrease the rate of metabolism of an algal organism, but this influence is only proportional to the amount of other stimuli that affect the rate of metabolism of a certain species, order, or phylum of algae.

Turbidity:

Standard Methods for the Examination of Water and Wastewater, eleventh edition (4b) states, "The turbidity of water is caused by the presence of suspened matter, such as clay, silt, finely divided organic matter, plankton, and other microscopic organisms. Turbidity should be clearly understood to be an expression of the optical property of a sample which causes light rays to be scattered and absorbed rather than transmitted in straight lines through the sample."

The highest turbidity, 950 turbidity units, was present in Geist Reservoir in March or April during the spring floods and caused an increase in turbidity for the entire reservoir. The euphotic zone is reduced to 1.5 feet by this high turbidity. Frey (1963) (11a) quotes (Wilson, 1941) that some species of aquatic plants require as much as 70 per cent of surface light, whereas others only need 2 per cent. Since the reservoir level at this time is usually between 1.0 and 2.0 feet above the dam, the submerged aquatic plants, if they could germinate, would probably not mature.

The effect of turbidity caused by increased inflow was investigated early in July 1964 following a rain of 0.73 inches. Tests were made longitudinally, cross-sectionally, and in depth. The influence of this turbidity was followed from station 111 to station 152. The upper strata were the first to become less turbid, and as the distance increased, the turbidity gradually decreased. As the turbidity approached the bottom of the reservoir, it was impossible to follow the turbidity by the sampling technique used. There is little doubt that the influence of turbidity existed further than could be tested. (See Table (4))

The damage caused by the high turbidities is shown by a study of mussel fauna carried out in September 1963. The only live specimens were found in section I. Numerous mussel shells were found in section II. The area where shells were found is approximately 1,000 feet from the old creek bed. This would indicate that this area was populated after the reservoir had filled. (Pennak, 1953) (13) says that an area

TABLE (4)

EFFECT OF A RAIN ON TURBIDITY

Sta.	Date	Depth (feet)	Turbidity Units	Date	Depth	Turbidity Units
13	7/9/64	0	200			
12	7/9/64	0	120			
		5	130			
151	7/9/64	0	120			
		5	130			
		10	150			
11	7/9/64	0	70			
		5	120			
		8	200			
10	7/9/64	0	75	7/10/64	0	20
		5	80		5	30
		9	130		9	200
9	7/9/64	0	50	7/10/64	0	25
		5	85		5	35
		9	190		9	130
8	7/9/64	0	30	7/10/64	0	30
		5	50		5	30
		9	120		9	140
152	7/9/64	0	30	7/10/64	0	30
		5	50		5	45
		10	90		10	80
		15	130		15	130
5				7/10/64	0	15
					10	20
					15	25
					19	170

of high turbidity is unsuitable for mussel fauna.

An article by Hasler, (1964) (12a) states that turbidity adversley effects ecological productivity and that it is possible to increase the depth of the euphotic zone by the use of hydrated lime. The hydrated lime treatment was given to Lake Peter of Peter-Paul Lake in Wisconsin. In one year's time, the depth of the euphotic zone was increased by 60 per cent and at the end of two years Lake Peter had a total increase of 160 per cent.

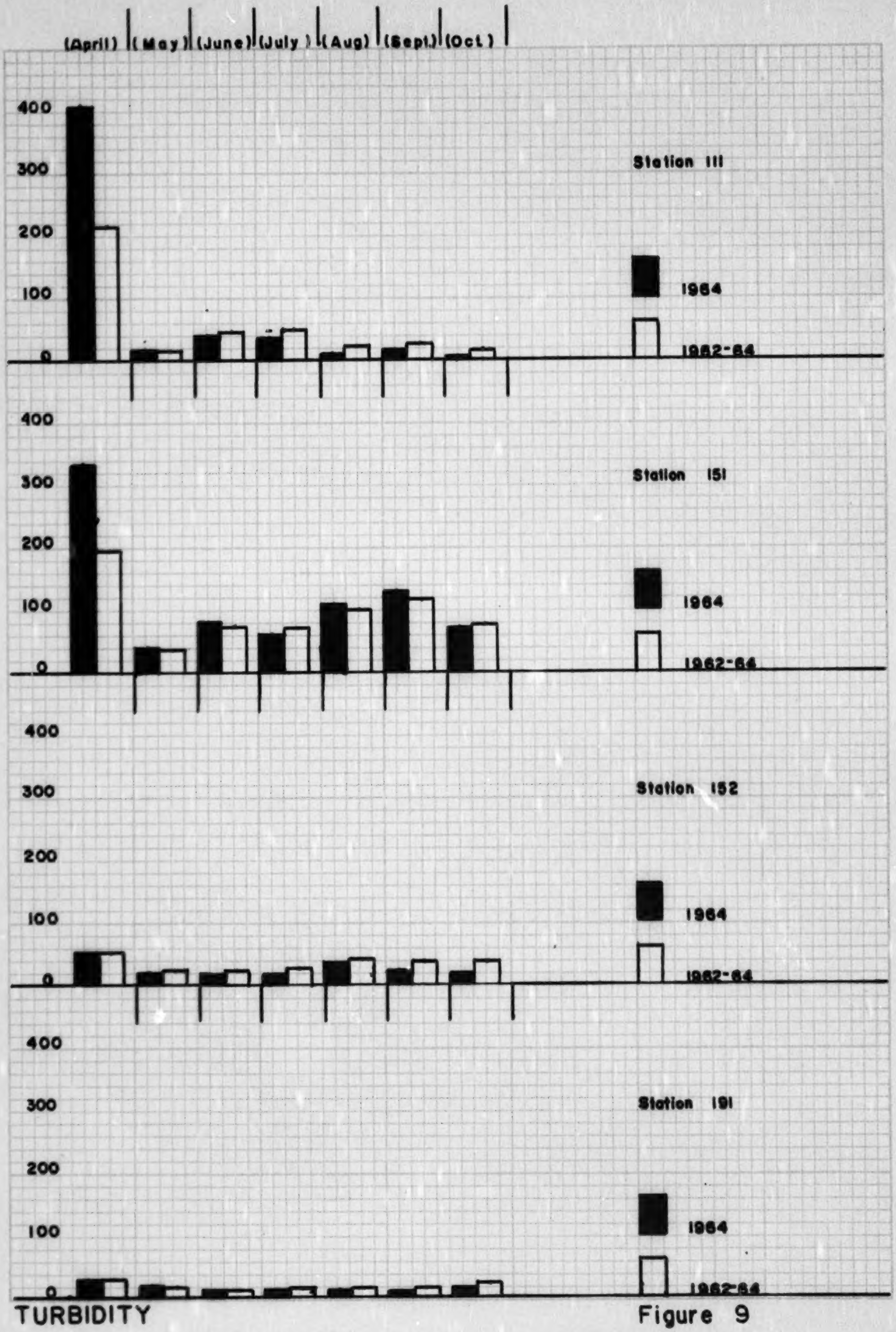
The high turbidities carried in by the spring floods have limited the ecological productivity of Geist Reservoir. The limiting affect is shown by:

a. The lack of aquatic plants in areas that are apparently suitable for growth.

b. A reduction in the spawning areas of game fish. (See Fish Productivity)

c. The fact that photosynthetic activity of algae starts at the lower end of the reservoir and gradually moves towards the inlet as the turbidity clears.

d. The variation in euphotic zone, from 1.5 feet during periods of maximum turbidity to a depth of 14 feet at minimum turbidity.



TURBIDITY

Figure 9

Eutrophication:

Eutrophication is usually associated with the maturity of a reservoir, (5a) and is the result of the enrichment of the water by nutrients. The aging process starts at the birth of a reservoir because of the leaching of nutrients from the bottom and the speed of this aging process is dependent upon the amount of inflow and pollutents in the basin.

Nutrients are nitrogen, phosphorus, alkalinity-hardness, silica, iron, cobalt, vitamins, etc.

Total nitrogen is the sum of organic and inorganic nitrogen. Organic nitrogen is usually associated with biological life, but this nitrogen can originate from industrial waste. Inorganic nitrogen is the sum of ammonia, nitrite and nitrate.

Total phosphorus is the sum of organic phosphate, usually polyphosphates, and soluble or orthophosphate. Organic phosphate, in most instances, is the phosphate present in biological life. Soluble phosphate is the readily available phosphate for biological life.

Table (5) shows the pounds of inorganic nitrogen and soluble phosphorus that entered Geist Reservoir during the calendar year 1964.

The surface area of Geist Reservoir is 1,800 acres. The inorganic nitrogen added to the Reservoir in 1964 was 441 pounds per acre of surface area. The soluble phosphorus equaled 21.3 pounds per acre of surface area.

Table (6) shows the amount of inorganic nitrogen and soluble phosphorus that was discharged from Geist Reservoir during the calendar

TABLE (5)

INFLOW OF NITROGEN AND PHOSPHORUS

Month	Average Inflow mgd	Inorganic ppm	Nitrogen pounds	Per Cent	N:P	Soluble ppm	Phosphorus pounds	Per Cent
January	31.8	0.32	2,630	0.3	2.0	0.157	1,290	3.4
February	23.4	1.42	8,210	1.0	4.2	0.339	1,920	5.0
March	469.7	4.37	530,680	66.9	55.3	0.079	9,590	25.1
April	631.6	0.65	102,720	12.9	7.5	0.087	13,750	35.9
May	109.8	1.48	42,010	5.3	14.2	0.104	2,950	7.7
June	40.6	2.75	27,930	3.6	15.9	0.173	1,760	4.6
July	107.6	2.39	66,490	8.4	39.8	0.060	1,670	4.4
August	11.2	0.59	1,710	0.2	2.3	0.256	740	1.9
September	8.3	1.06	2,200	0.3	3.6	0.327	680	1.8
October	13.8	0.66	2,360	0.3	2.2	0.297	1,060	2.8
November	23.6	0.92	5,430	0.7	4.3	0.212	1,250	3.2
December	24.2	0.14	880	0.1	0.5	0.258	1,610	4.2
TOTAL			793,250	100.0	20.7		38,270	100.0

TABLE (6)

OUTFLOW OF NITROGEN AND PHOSPHORUS

Month	Discharge Ave. mgd	Inorganic ppm	Nitrogen pounds	Per Cent	N:P	Soluble ppm	Phosphorus pounds	Per Cent
January	19.6	0.02	100	0.1	0.7	0.029	150	0.6
February	20.7	0.29	1,450	0.3	6.4	0.045	220	0.9
March	378.4	1.66	162,400	36.6	41.5	0.040	3,910	16.6
April	624.9	1.36	212,640	48.0	12.3	0.110	17,360	73.7
May	118.2	0.67	20,470	4.6	33.5	0.020	610	2.6
June	45.4	2.90	32,940	7.4	290.0	0.010	110	0.4
July	105.4	0.26	7,080	1.6	52.0	0.005	140	0.6
August	35.5	0.12	1,100	0.3	4.0	0.030	280	1.2
September	35.7	0.16	1,430	0.3	6.6	0.024	210	0.9
October	33.2	0.24	2,060	0.5	6.5	0.037	320	1.4
November	21.9	0.17	930	0.2	5.9	0.029	160	0.7
December	20.5	0.10	530	0.1	5.2	0.019	100	0.4
TOTAL			443,130	100.0	18.8		23,570	100.0

year 1964.

The retention of inorganic nitrogen is equal to the inflow minus the discharge or 350,120 pounds. This weight is equivalent to 194 pounds per acre of surface area. (See Table (7))

The retention of soluble phosphorus is 14,700 pounds or 8.2 pounds per acre of surface area. (See Table (7))

TABLE (7)

NUTRIENTS RETAINED

1964	Inorganic Nitrogen pounds	Inorganic Nitrogen Per Cent	N:P	Soluble Phosphorus pounds	Soluble Phosphorus Per Cent
January	2,630	0.7	2.2	1,140	7.8
February	6,760	1.9	4.0	1,700	11.6
March	368,280	105.2	64.8	5,680	38.6
April	-109,920	-31.4		-3,610	-24.4
May	21,540	6.2	9.2	2,340	15.9
June	-5,010	-1.5		1,650	11.2
July	59,410	17.0	38.8	1,530	10.4
August	610	0.2	1.3	460	3.1
September	770	0.2	1.6	470	3.2
October	300	0.1	0.4	740	5.0
November	4,500	1.3	4.1	1,090	7.4
December	350	0.1	0.2	1,510	10.2
TOTAL	350,120	100.0	23.8	14,700	100.0

Geist Reservoir is 22 years old. A reasonable assumption is that the leaching of the original bottom soil has stopped. Thus the mineral content in Geist Reservoir's water is from recirculation of the minerals that have deposited on the bottom of the reservoir, the minerals that are in solution or that are introduced by the inflow water.

Normally there are three major ways nutrients can enter a stream--

TABLE (8)

NUTRIENTS CONTRIBUTORS

Source	Total Nitrogen	Total Phosphorus
Corn 20% Slope	38lbs/Acre/Year	1.8lbs/Acre/Year
Corn 8% Slope	18lbs/Acre/Year	0.5lbs/Acre/Year
Kentucky Blue Grass	0.3-12lbs/Acre/Year	
Alfalfa	0-10lbs/Acre/Year	
Bare Ground	29-169lbs/Acre/Year	
Cattle	156lbs/1000lbs live wt	17lbs/1000lbs live wt
Hogs	150lbs/1000lbs live wt	45lbs/1000lbs live wt
Domestic Sewage	6-12lbs/Person/Year	2-4lbs/Person/Year (3lbs)
Rain Water	5.5lbs/Acre of Reservoir	
Killed Algae (Summer Maximum)	24lbs/Acre	2.4lbs/Acre
Killed Submerged Plants	32lbs/Acre	3.2lbs/Acre
Killed Fish	50lbs/Ton	4lbs/Ton

runoff, sewage, and ground water. Table (8) is taken from Mackenthun et al (1964) (14a) and a verbal communication from Kenneth M. Mackenthun.

Table (9) lists the type and acreage of each crop grown in the reservoir's drainage basin. Table (10) lists the number and kinds of livestock raised in Geist drainage area.

The information shown in Table (9) and (10) concerning the sources of nutrient was compiled from data received from the county agents.

TABLE (9)

ESTIMATE OF NITROGEN AND PHOSPHATE FROM CROPS

Crops etc.	Acres	lbs of Nitrogen Per Acre	Total	lbs of Phosphorus Per Acre	Total
Corn 8% Slope	41,700	18	751,000	0.50	20,850
Wheat and Oats	22,000	8 (est)	178,400	0.25 (est)	5,500
Soybeans	28,000	12 (est)	336,000	0.30 (est)	8,400
Pasture	23,000	6	138,000	0.20 (est)	4,600
Forest and Uncultivated	21,000	6 (est)	105,000	0.10 (est)	2,100
TOTAL			1,508,400		41,450

TABLE (10)

ESTIMATE OF NITROGEN AND PHOSPHATE FROM LIVESTOCK

		Pounds of Nitrogen		Pounds of Phosphorus	
Type of Livestock	Number of Heads	Per 1000 Live Wt.	Total	Per 1000 Live Wt.	Total
Cattle	15,000	156	2,340,000	17	255,000
Hogs	24,000	150	720,000	45	216,000
TOTAL			3,060,000		471,000

The information concerning the average live weights was calculated from the following information received from the Indianapolis Stock Yards:

Cattle--Steers varied from 900 to 1,500 pounds.

Heifers averaged 800 pounds.

The average head was estimated at 1,000 pounds.

Hogs----Varied from 190 to 240 pounds.

Average hog was estimated at 200 pounds.

There are approximately 22,000 people living on farms and a total of 1,500 people living in two communities that do not have sewers. The 23,500 people use some type of soil absorption disposal system for their sewage. The amount of nutrients that leach out of the soil and enter the reservoir is not known.

Three sewered communities and one institution discharged treated sewage into Fall Creek as shown in Table (11).

TABLE (11)

NUTRIENTS FROM SEWERED COMMUNITIES

Community or Institution	P. E. before Treatment	Nitrogen PE	Nitrogen Pounds	Phosphorus PE	Phosphorus Pounds
Fortville	2,000	9	18,000	3	6,000
Indiana Reformatory	3,300	9	29,700	3	6,600
Pendleton	3,750	9	33,750	3	8,250
Middleton	2,000	9	18,000	3	6,000
TOTAL	11,050		99,450		26,850

The total estimated nitrogen and phosphorus present in Geist Reservoir drainage basin is given in Table (12).

TABLE (12)

NUTRIENTS AVAILABLE IN DRAINAGE BASIN

Source	Nitrogen Pounds	Per Cent	Phosphorus Pounds	Per Cent
Crops	1,508,400	32.3	41,450	7.4
Cattle	3,060,000	65.6	471,000	87.8
Sewered P. E.	99,450	2.1	26,850	4.8
TOTAL	4,667,850	100.0	559,300	100.0

If all of the nitrogen, 99,450 pounds, discharged from the sewered population equivalents entered the reservoir, the amount would be less than 12 per cent of the total nitrogen entering the reservoir. This figure indicates that most of the nitrogen entering the reservoir is carried in from land runoff.

Of the 38,270 pounds of total soluble phosphorus that enter the reservoir approximately 70 per cent comes from the sewered population equivalents.

A comparison with a previous study is made below to illustrate the eutrophication of Geist Reservoir. The Madison Lakes, Lake Mendota, Lake Monona, Lake Waubesa, and Lake Kegonsa have been extensively studied. The Wisconsin Governor's Committee in 1942 instituted a two year study, (14b) 1942 and 1943, to investigate the problem of the fertilization of waste of the three lower lakes. This study was prompted by the excessive and obnoxious algal growths that plagued the local residents.

Table (13) and (14) are a comparison between the Madison Lakes and Geist Reservoir. Table (15) is also a comparison between the Wisconsin Lakes and Geist Reservoir on a percentage basis. Lake Waubesa, the most heavily polluted, was used as the standard for comparison.

When the inorganic nitrogen input per acre figures are compared, Geist Reservoir is potentially as enriched as the most polluted of these lakes, see Table (13). Mackenthun et al (1964) (14c) state "In a study of the lower Madison Lakes, Sawyer et al, and Lackey and Sawyer (1945) found that the annual contribution of inorganic nitrogen per acre of drainage area tributary to Lake Monona was 4.4 pounds, Lake Waubesa 4.9 pounds, and Lake Kegonsa 6.4 pounds." Geist Reservoir drainage area of 137,000 acres shows a contribution of inorganic nitrogen per acre of 5.8 pounds based on 1964 inflow data. As stated above these lower Madison Lakes are damaged by algal blooms.

Mackenthun et al (1964) (14d) quotes Sawyer (1947) that 0.30 ppm of inorganic nitrogen (N) and 0.01 ppm of soluble phosphorus (P) at the beginning of the active growning season may cause algal blooms.

Algal blooms caused by diatoms, greens or pigmented flagellates can be observed almost any time except when high turbidities occur or during a prolonged drought. Diatom blooms of Cyclotella, Diatoma, Melosira and Synedra have occurred. Green blooms of Pediastrum, Spirogyra, and Rhizodonium have been observed. Pigmented flagellates that have caused blooms, are Euglena acus, Euglena sp., Peridinium bipes

TABLE (13)

INORGANIC NITROGEN (3e) (14i)

	Inflow		Retention		
Lakes or Reservoir	lbs/Yr	lbs/A/Yr	Per Cent	lbs/Yr	lbs/A/Yr
Mendota (1949)	259,720	27	81	221,042	22
Monona (1942-43)	254,028	73			
(1943-44)	313,573	90	70	219,501	63
Waubesa (1942-43)	859,113	422			
(1943-44)	911,085	448	64	583,094	287
Kegonsa (1942-43)	527,014	168			
(1943-44)	490,524	156	61	299,220	95
Geist (1964)	793,250	441	44	350,120	194

TABLE (14)

SOLUBLE PHOSPHORUS (3e) (14i)

	Inflow		Retention		
Lakes or Reservoir	lbs/Yr	lbs/A/Yr	Per Cent	lbs/Yr	lbs/A/Yr
Mendota (1949)	17,362	1.8	47.7	8,282	0.9
Monona (1942-43)	23,072	6.6			
(1943-44)	29,601	8.5	88.0	26,050	7.5
Waubesa (1942-43)	125,384	62.0			
(1943-44)	129,366	63.6	25.0	32,341	15.9
Kegonsa (1942-43)	107,864	34.2			
(1943-44)	118,874	37.7	12.0	14,265	4.5
Geist (1964)	38,270	21.3	38.4	14,700	8.2

TABLE (15)

RELATIONSHIP OF GEIST RESERVOIR WITH MADISON LAKES

Lakes or Reservoir	Inflow Inorganic N lbs/A/Yr	 Per Cent	 Soluble P N:P	 lbs/A/Yr	 Per Cent	Retention Inorganic N lbs/A/Yr	 Per Cent	 Soluble P N:P	 lbs/A/Yr	 Per Cent
Mendota (1949)	27	60	15:1	1.8	3	22	8	24:1	0.9	6
Monona (1943-44)	90	20	11:1	8.3	13	63	22	8:1	7.5	47
Waubesa (1943-44)	448	100	7:1	63.6	100	287	100	18:1	15.9	100
Kegonsa (1943-44)	156	35	4:1	37.7	59	95	33	21:1	4.5	28
Geist (1964)	441	98	21:1	21.3	33	194	68	24:1	8.2	52

and Ceratium cornutum.

Algal mats of Rhizodonium occurred in September, 1963, along one side of the reservoir for approximately 7 miles, and extended a few feet from the bank to approximately 30 feet. This alga is a filamentous type which grows in eutrophic, shallow, hard water. The large area covered with these algal mats could possibly be caused by the drought conditions.

In the two and one-half years Geist Reservoir has been studied, no blue-green algal blooms have been observed. The Cyanophyta are not numerous when compared with the total ppm. The blue-green algae are found in late summer and fall seasons in Geist Reservoir. Since nitrogen, phosphorus, and alkalinity are present, the absence of a blue-green bloom would suggest that some necessary trace element is lacking.

Previous to the Indiana Water Quality Recreation Project, Mr. Robert Becker, superintendent of the Indianapolis Water Company, filtration department, recalled a Synura bloom under the ice of Geist Reservoir which caused a difficult taste and odor problem.

Geist Reservoir water has not been difficult to treat for taste and odor during the study. The raw water intake for the water purification plant is located downstream approximately 8 river miles; therefore some of the nuisance type algae do not reach the plant. Most of the odor and taste in the raw water can be masked by break point chlorination. For a number of days each year, heated potable water will give off an aromatic, earthy, grassy, or musty odor. On a few occasions activated carbon had to be used because of taste and odor. Some of these offensive taste and odors have been traced to sources other than Geist Reservoir.

Short filter runs do occur for short periods of time. The short filter runs for the most part have not been traced to the algae in the reservoir.

Geist Reservoir's aquatic plant, other than algae, have not been numerous for the last three years. They are only found in isolated areas that have been protected from turbidity.

If it is assumed, that all the inorganic nitrogen and soluble phosphorus retained in Geist Reservoir is used by the "net algae"; then, the other aquatic organisms fill their nitrogen and phosphorus needs from recirculation of precipitated nutrients or they are able to utilize an organic form of nitrogen and phosphorus. Hasler (1963) (3b) states, "It is a well known axiom in limnology that a lake is generally wasteful of phosphorus that enters it via effluents from the surrounding watershed. In fact, the bottom water and mud of these lakes contain sufficient nutrients to bring them into a eutrophic condition, but owing to the seasonal stratification of the water, nutrients accumulate near or on the bottom of the basin, where they are unavailable to the aquatic organisms in the euphotic zone above".

Geist Reservoir is not stratified and the water is usually mixed several times a season during open water periods.

Hasler (1963) (3c) indicates that approximately 4 per cent of the dry weight of some algal forms is nitrogen. Mackenthun et al (1964) (14e) quoting Gerloff and Skogg state that 6.8 per cent of the dry weight of blue-green algae is nitrogen.

Based on the inorganic nitrogen retained in Geist Reservoir, 350,120 pounds, and using the 4 per cent figure, 8.75 million pounds of "net algae", dry weight, was produced in 1964. The 8.75 million pounds of "net algae" would be equal to 4,860 pounds per acre of surface area per year.

Mackenthun et al (1964) (14f) state that the algae and aquatic plants, in their natural habitat, have a ratio of approximately 10 nitrogen to 1 phosphorus. Mackenthun et al (1964) (14e) discussing Birge and Juday's (1922) work states that the dry weight of algae is approximately 10 per cent of the wet weight.

Based on the soluble phosphorus retained in the reservoir, 14,700 pounds, and using the 10:1 ratio and the 4 per cent nitrogen figure, the "net algae" weight would be 3.68 million pounds, dry weight or 2,040 pounds per acre per year. The "net algae" dry weight for 1964 based on soluble phosphorus is only 42 per cent as much as the amount found for the inorganic nitrogen.

Frey (1963) (11b) discussing Juday's work, assumed the phytoplankton to have a turnover rate of one time per week. Welch (1952) (5d) discussing a similar work of Birge and Juday, assumed the turnover rate was 50 times per year.

Geist Reservoir's wet weight for "net algae" was 23.2 ppm in 1964. The average euphotic zone water weight was 30,800 million pounds. Based on 30,800 million pounds of water, the 2.32 ppm for dry weight of the "net algae", and a turnover rate 52 times per year, the total dry weight of the "net algae" would be 3.71 million pounds or 2,060 pounds per acre of surface area per year.

Maddux and Jones (1964) (9) established doubling rates for two salt water species of algae for different temperatures, inorganic nitrogen, soluble phosphorus, and light intensity. A doubling rate is the frequency a specific algal species will multiply in a given time limit. Based on their work, an attempt was made to project the doubling rate for other algae. This projection is crude but it is an attempt to give some insight into algal production.

Based on the estimated average doubling rates for each month, the average algal mass, ppm (volume) for each month, and each month's average water weight in the euphotic zone, the calculated dry weight of "net algae" for 1964 was 4.30 million pounds or 2,390 pounds per acre of surface area per year.

The 3.68 million pounds (dry weight) of "net algae", based on the amount of retained soluble phosphorus, is compared with 3.71 and 4.30 million pounds (dry weight) that are based on algal mass figures; hence, the reasonable assumption would be that the soluble phosphorus is one of the controlling factors for algal production in Geist Reservoir. Based on the soluble phosphate retained in the reservoir each population equivalent would approximately equal 300 pounds of dry weight of "net algae".

Mackenthun et al (1964) (14g) quotes (Hasler 1947) "It is clear that any increase in the rate of eutrophy, even if this involves only the acceleration of a natural and inevitable process is, from a human point of view, thoroughly undesirable".

If Geist Reservoir drainage basin follows the projected population trend, the projected increase in cattle, and the new technological developments in agriculture, the increase in algae can only cause further deterioration in the water quality. See Figure 10. Fresh water, could be damaged to a point that the cost of treatment could approach the cost of processing sea water.

A reservoir for a water supply has one primary function, to supply the best quality of water possible in an adequate quantity to a purification plant. All other uses of the reservoir are secondary to the primary function. Using the land adjacent to a reservoir for housing could be damaging to the water quality, unless, the sewage treatment is the best possible and the runoff water is strictly controlled. The use of unrestricted recreation such as, picnic areas, camp sites, cabin boats, and unrestricted bathing could be damaging.

The amount of algae and nutrients in Geist Reservoir could be a two-edged sword. An increase in nutrients would probably lead to an increase in algal blooms. Mackenthun et al (1964) (14h) points out that algal blooms could become a nusiance which could produce obnoxious odors from algal mats, taste and odor in the water, fish kills, and possibly troublesome increases in the aquatic insect population. Quoting Mackenthun et al (1964) (14i) further: "Rapid decomposition of dense algal scums with associated organisms and debris gives rise to odors and hydrogen sulfide gas that create strong citizen disapproval; often the gas stains the white lead paint on residences adjacent to the shore to ugly hues of gray and even black".

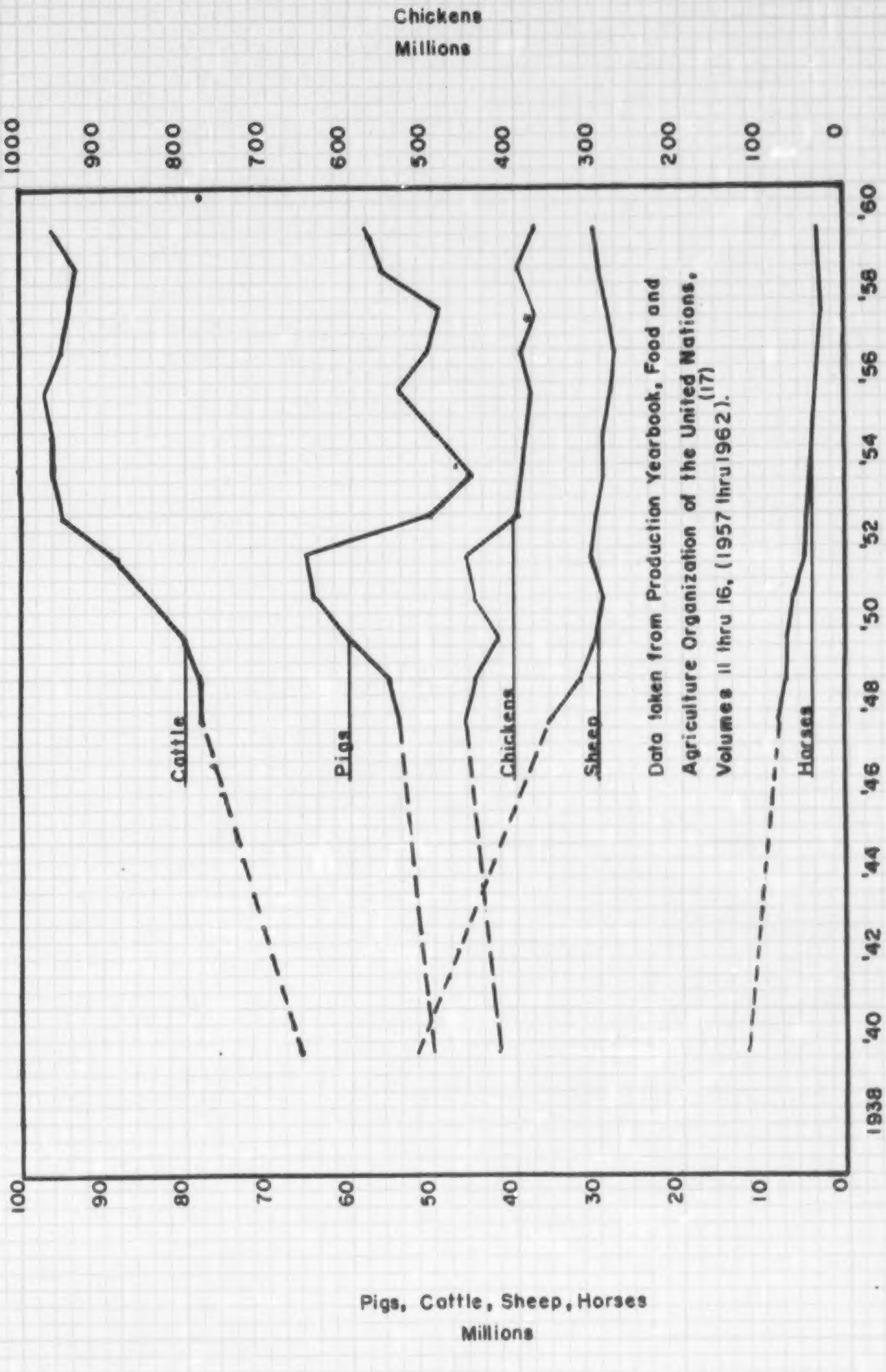
Hasler (1963) (3d) points out that 95 to 99 per cent of the soluble phosphorus in sewage can be precipitated with 200 ppm of alum. Some of the ammonia and nitrate nitrogen in sewage can be removed by ion exchange columns. All these methods are costly but the point is which is the more costly--heavy algal laden water that is expensive to treat, for water supply, or more elaborate sewage treatment. Of course the effects of algae etc. on man's environment has to be considered.

Agricultural pollution has been recognized for sometime by the U. S. Public Health Service. The Kansas River Basin Report (June 1949) (15) recognized that the surface water runoff from farm land could cause an increase in the total coliform counts and increase the biochemical oxygen demand. Neel (1953) (16) points out that the reuse of water for irrigation increased the mineral content and the turbidity. The College of Engineering of the University of Missouri, received a grant from the U. S. Public Health Service to determine the population equivalents and possible sewage disposal for livestock waste.

Jeffrey et al (1964) (17) says the trend in livestock raising will be for the closer confinement of animals with an increase in livestock population. At the present time only a small fraction of the livestock is raised in confinement. It has been proven that hogs can be marketed cheaper by use of "Hog Parlors".

"Hog Parlors" caused a problem of waste disposal. To solve this problem waste disposal pits called anaerobic lagoons were built next to the concrete floor of the "Hog Parlors". In Missouri they are usually

FARM ANIMAL POPULATION in U.S. 1939 to 1959



Data taken from Production Yearbook, Food and Agriculture Organization of the United Nations, Volumes 11 thru 16, (1957 thru 1962).(17)

Figure 10

5 feet deep with a surface area of 15 square feet per hog. Many of these anaerobic lagoons do not overflow.

LeGrand (1965) (18) points out the danger of contaminating the ground water by lagoons. If the nutrients are not removed by the soil, then these nutrients could be discharged into a stream.

Henry H. Krusekopf, University of Missouri professor emeritus of soils, pointed out that many soils have been damaged by leaching. Soils that have the highest content of organic matter are neutral or only slightly acid and contain a high per cent of exchangeable calcium. The soil that has organic matter, humus, is the type that will not be affected as readily by leaching. Therefore the per cent of nutrients, nitrogen, phosphate, and potash, will be greater in the soil; thus less fertilizer will be needed to develop a good crop. He suggests the crop residue and barnyard manure be plowed into the soil.

A newer method of raising corn was observed by the project biologist in Missouri. In an experimental plot, corn was planted, fertilized and cultivated by the accepted method. In the same plot, after the area was prepared, the corn was planted, fertilized and a granular weedicide was added all at the same time. The second type of corn raising was not touched until it was harvested. The yield was greater and the stalks were higher in the area treated with weedicide. No doubt the soil wash was not as great as the conventional method of growing corn. Whether this weedicide will damage ground water or a waterway is a question that has to be answered before the method can be accepted.

Much more diligent work should be done to reduce agricultural pollution. Old ideas and methods must be improved to reduce the pollution load on the streams. Possibly the idea of planting cover crops on hillsides, terracing, and more numerous farm ponds would help alleviate this problem.

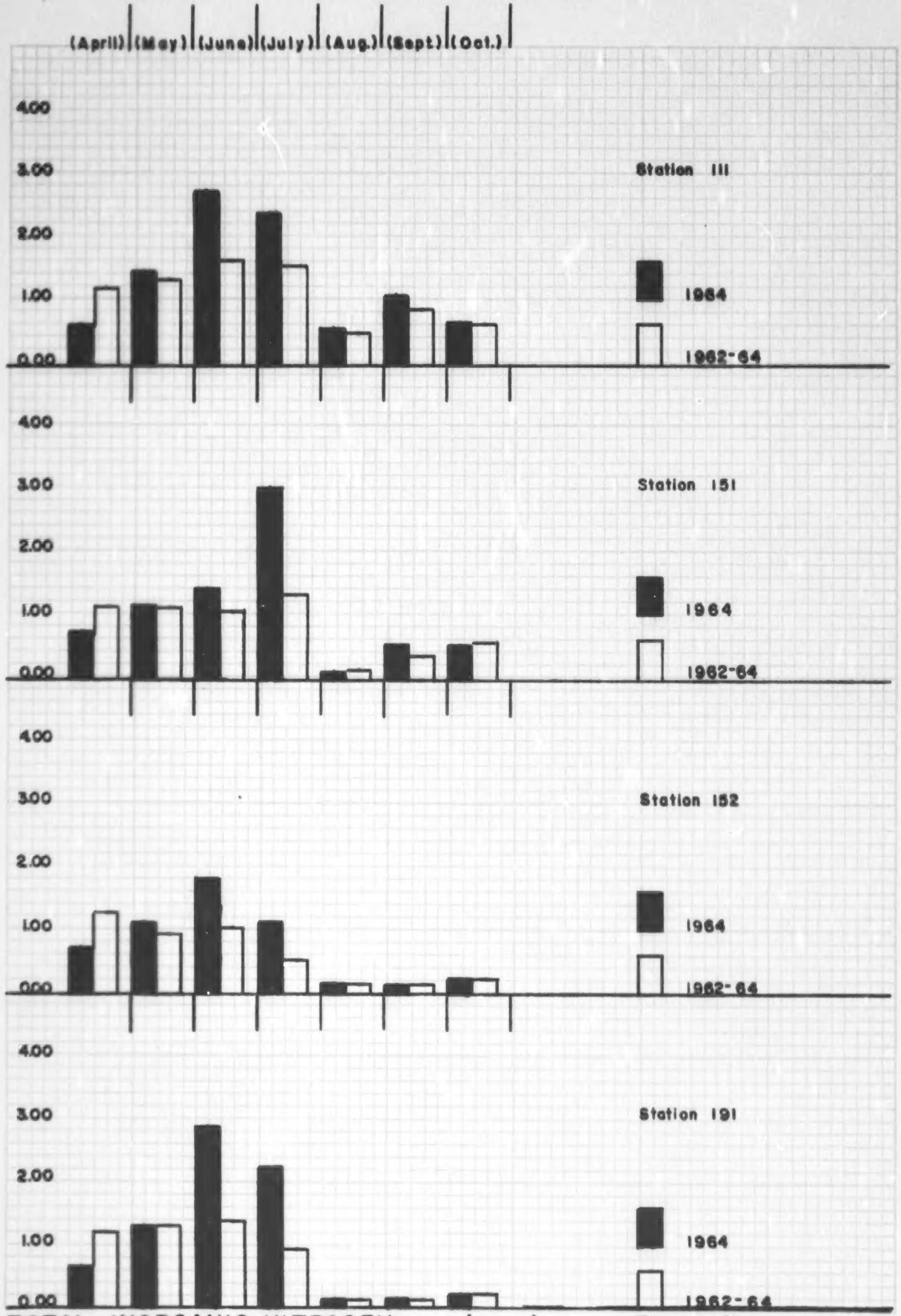
Mineral analysis of runoff water includes important chemicals other than nitrogen and phosphorus.

A form of carbon dioxide is needed in the photosynthetic reaction. Carbon dioxide is supplied by bacterial action, the atmosphere, aquatic life, and bicarbonate alkalinity. Insoluble carbonates are formed at the expense of the bicarbonate alkalinity because of photosynthesis. The deposits of Carbonates reduce the capacity of Geist Reservoir. See Table (16).

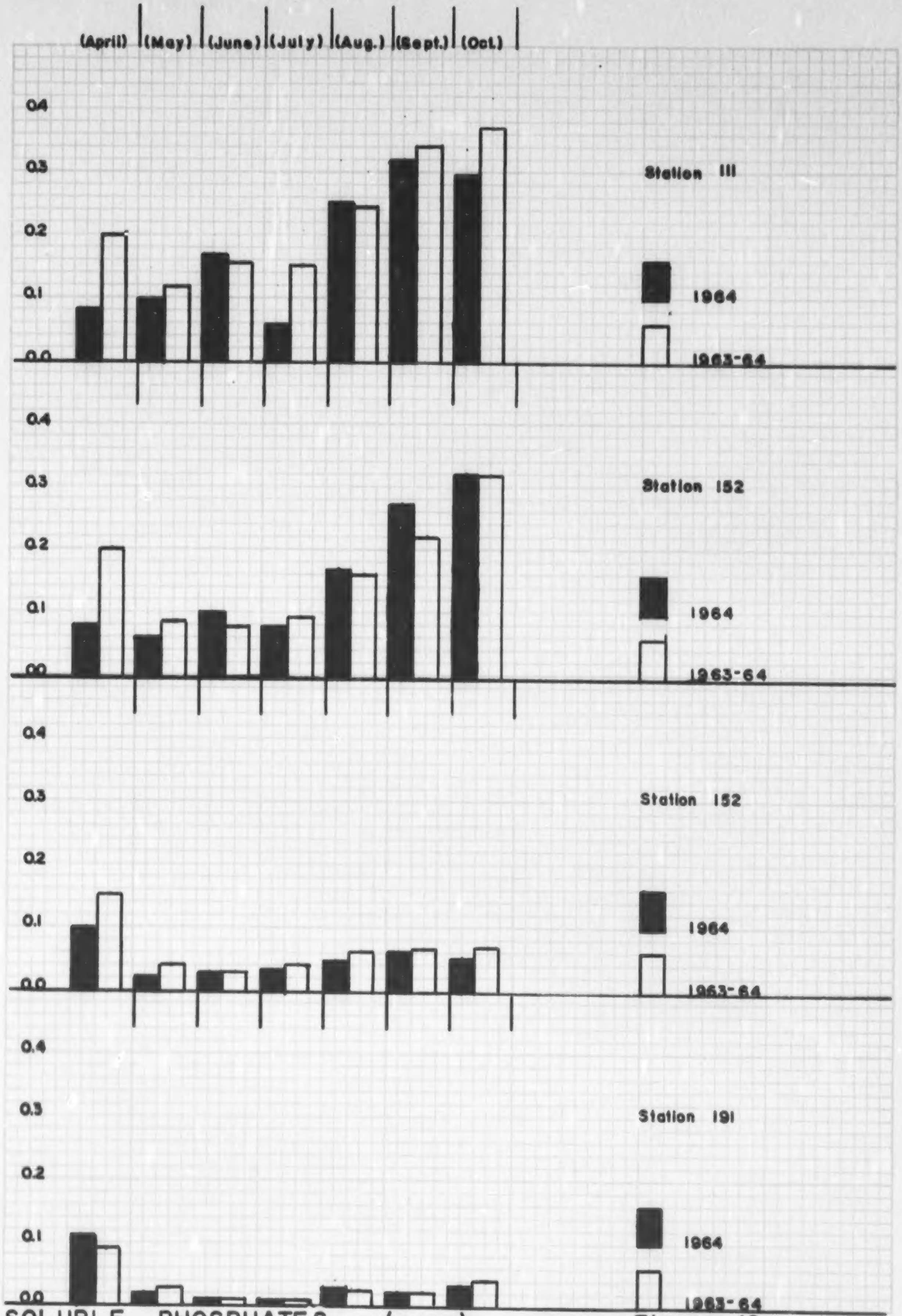
TABLE (16)

ALKALINITY

	Inflow			Discharge		
Month	Water Million lbs	ppm C_aCO_3	Alkalinity Million lbs	Water Million lbs	ppm C_aCO_3	Alkalinity Million lbs
Jan.	8,215	233	1.914	5,053	176	0.889
Feb.	5,655	277	1.566	4,988	216	1.077
March	121,303	151	18.317	97,712	141	13.777
April	157,830	93	14.678	156,150	102	15.927
May	28,365	235	6.666	30,535	143	4.369
June	10,140	251	2.545	11,340	180	2.041
July	27,776	236	6.555	27,218	138	3.756
Aug.	2,883	290	0.836	9,176	156	1.431
Sept.	2,070	261	0.540	8,910	146	1.301
Oct.	3,565	267	0.952	8,587	158	1.357
Nov.	5,910	246	1.454	5,460	162	0.884
Dec.	6,262	268	1.678	5,301	168	0.891
TOTAL			57.701			47.700

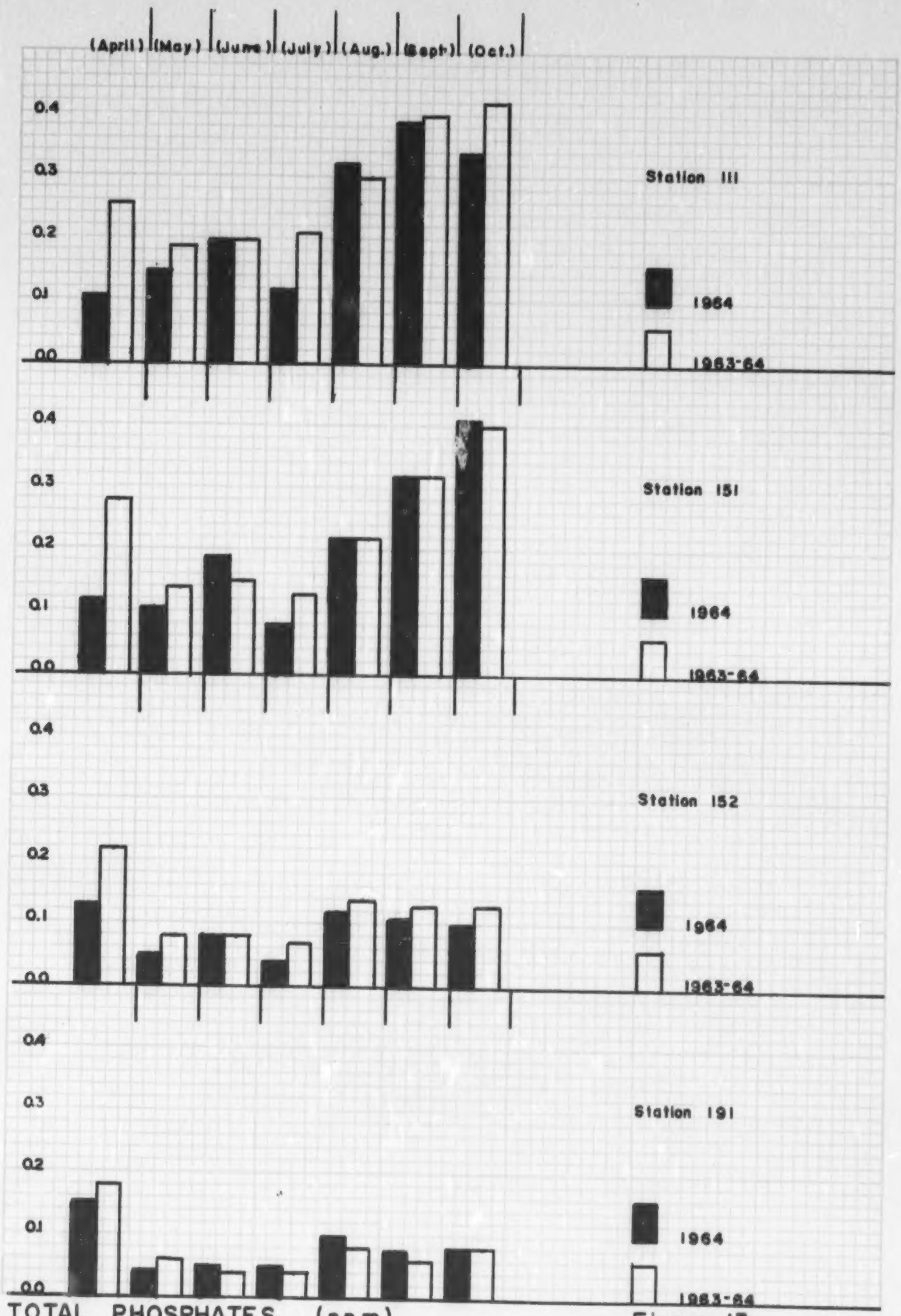


TOTAL INORGANIC NITROGEN (p.p.m.) Figure II



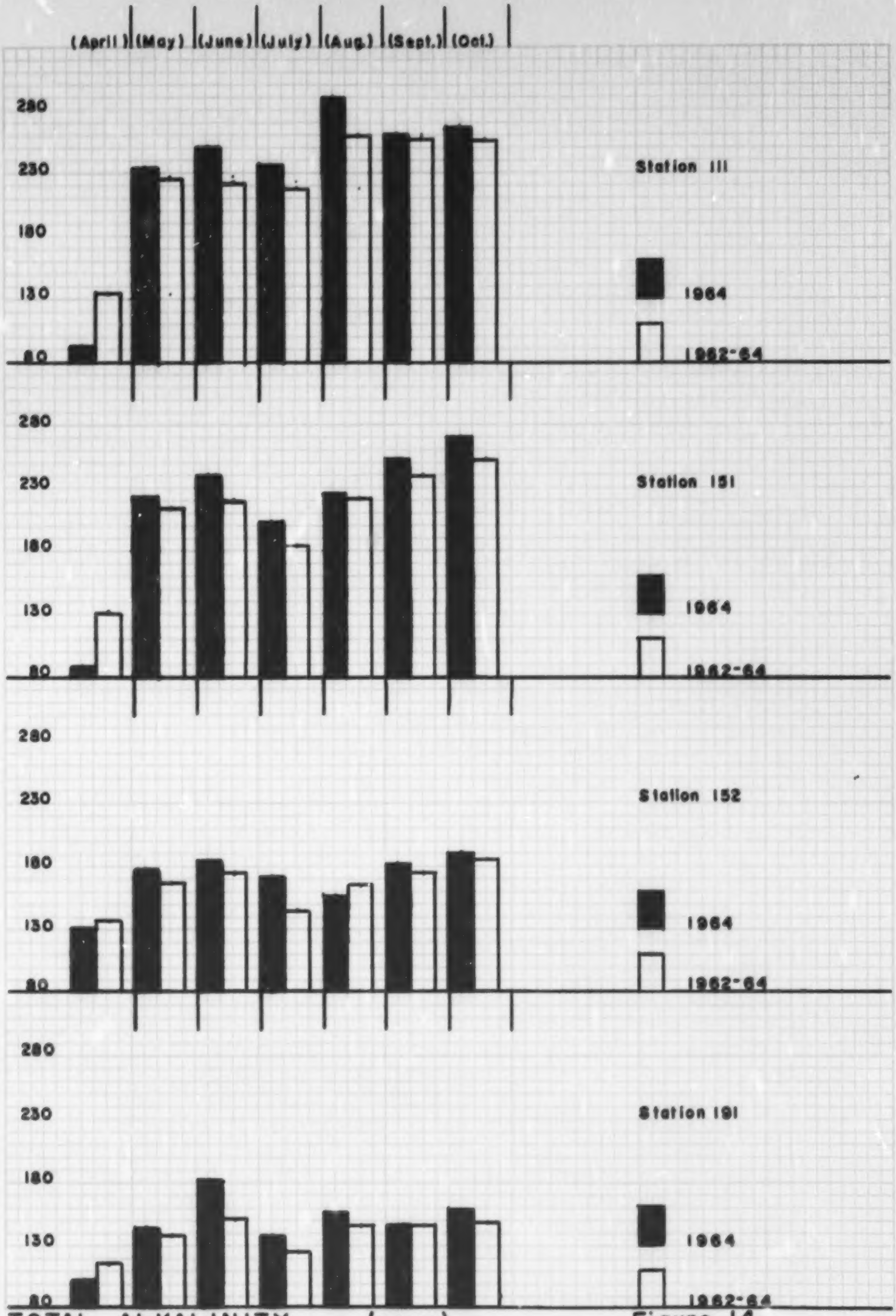
SOLUBLE PHOSPHATES (p.p.m.)

Figure 12

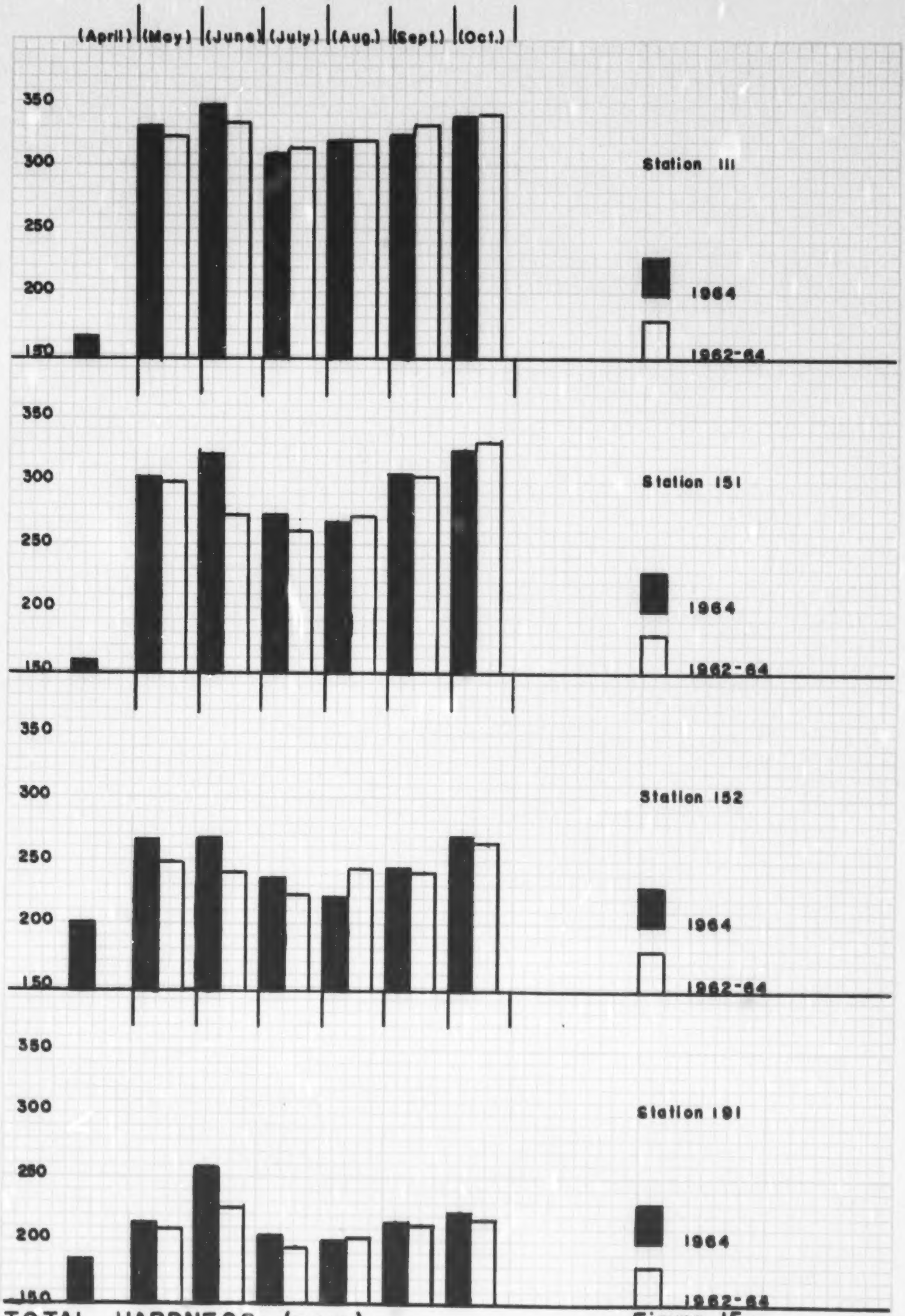


TOTAL PHOSPHATES (p.p.m.)

Figure 13



TOTAL ALKALINITY (p.p.m.) Figure 14



TOTAL HARDNESS (p.p.m.)

Figure 15

TABLE (17)

GROSS MINERAL ANALYSES ppm

INFLOW

Sta	Date	ABS	Na	K	Ca	Mg	SiO$_2$	Total Fe	SO$_4$	Cu	Cd	Ni	Zn	Pb	Total Cr	COD
111	4/29	0.03	5.6	1.3	40	37	5.2	0.29	60	0.13	x	x	0.05	0.08	0.01	13.4
	6/25	0.09	8.8	1.5	51	40	7.2	1.48	59	0.02	x	0.01	x	0.05	0.02	12.4
	8/25	0.07	6.0	2.1	75	44	8.2	3.00	56	0.05	x	0.01	x	0.10	x	21.7
	10/10	0.11	14.8	2.7	79	45	5.8	1.58	54	0.02	x	x	x	0.03	x	18.2

DISCHARGE

Sta	Date	ABS	Na	K	Ca	Mg	SiO$_2$	Total Fe	SO$_4$	Cu	Cd	Ni	Zn	Pb	Total Cr	COD
191	4/29	0.03	4.0	1.9	34	24	3.3	0.16	46	0.18	x	x	0.03	0.06	x	20.0
	6/25	0.17	5.0	1.7	32	32	2.2	0.10	48	0.07	x	0.01	0.04	0.36	x	18.7
	8/25	0.05	6.3	2.2	37	33	0.6	0.16	42	0.04	x	x	x	0.03	x	33.4
	10/10	0.07	7.0	1.8	41	34	1.6	0.50	46	x	x	x	x	0.04	x	29.0

x---None found at a sensitivity of 0.01 ppm.

TABLE (18)

RECOMMENDED LIMITS

ABS	Nitrate as		Fe	SO$_4$	Cu	Cd	Zn	Pb	Hexavalent Cr
	NO$_3$	N	(not total)						(not total)
0.50	45	10	0.30	250	1.00	0.01	5.0	0.05	0.05

The retention of "alkalinity" is 10.001 million pounds. The inflow alkalinity is equivalent to 32,056 pounds per acre of surface area. The retention of alkalinity is equal to 5,556 pounds per acre of surface area.

Table (17) shows the results of Gross Mineral Analyses conducted by the chemical laboratory of the Great Lakes-Illinois River Basin Project during calendar year 1963. The results are from 4 sets of samples which is not a sufficient number to evaluate, nor are they necessarily a reflection of the chemical analysis of the potable water. For ease of comparison, Table (18) lists some of the limits recommended by the U. S. Public Health Service for drinking water.

The 1964 benthic organisms data shows the lower section, section I as the most productive. The 1963 data indicated the lower section of section II as the most productive. From other data it would appear that the 1964 data gives a more accuracy picture of the reservoir.

If this interpretation of data is correct, then the evidence would indicate that section II is now on the decline and the benthic organism are showing a preference for section I.

Productivity of Fish:

Mr. Robert Boots, a State Conservation Officer, and personnel at County Line Dock stated that the following species of fish are present in Geist Reservoir. (Table (19))

When Geist Reservoir was initially filled, there were a moderate number of Rock Bass and Warmouth Bass present in Fall Creek. These fish found their way into the reservoir. There was a harvest of Rock

TABLE (19)

FISH IN GEIST RESERVOIR

Type of Fish	Number	Size	Catch
Largemouth Bass	Decreasing	Large (some decline)	Poor
Smallmouth Bass	Decreasing	Decreasing	Poor
Crappie	Increasing	Increasing	Good
Bluegill	Increasing	Stunted	Poor
Green Sunfish	Decreasing	Small	Poor
Yellow Perch*	Increasing	Increasing	Few
Channel Catfish	Increasing	Increasing	Good
Blue Catfish	Increasing	Increasing	Good
Flathead Catfish	Decreasing	Smaller	Fair
Bullhead Catfish	Decreasing	Smaller	Fair
Grass Pickerel	Small	Small	Poor
Carp	Increasing	Increasing	Good
Suckers	Decreasing	Decreasing	Poor
Shad	Increasing	Increasing	----

* Stocked in last few years.

Table (20) lists the largest catch of the year.

TABLE (20)

GEIST RESERVOIR "LARGEST CATCH OF THE YEAR"

	1962		1963		1964	
	Inches	Ounces	Inches	Ounces	Inches	Ounces
Bluegill	8.5	7	8.5	7	8.5	7
Largemouth Bass	23	96	22	112	21	75
Crappie	16.5	188 ?	18	36	17.5	42
Catfish	34	284	36	332	35	307
Carp	33	276	30	307	34	320

Bass for a number of years, but for the last five years, there has been no report of this fish being caught. The last report of a Warmouth Bass being caught was in 1963.

The Bluegill are stunted and are increasing in number whereas the bass are large and decreasing in number. Denney (1963) quotes Swingle (19) who refers to this condition of the fish population as being "unbalanced". The literature gives several methods for the correction of stunted fish. Most of the suggested procedures are not suitable for a lake or reservoir that is used for a potable water supply.

Fish are in "balance" when the forage species continue to supply the carnivorous species adequately and still reproduce without any of the species becoming stunted. This condition must continue year after year to produce a satisfactory amount of harvestable fish. Denney (1963) gives Swingle's (1956A) (19) list of a number of ways in which the "balance", ratio of predators to forage fish, can become unbalanced:

1. Large brood stock of one species.
2. Availability of food one to three months before spawning.
3. Crowding caused by over-production of one or more species and some species eating fish eggs.
4. Water temperature, not suitable for spawning.
5. Silt-laden water.
6. Water level fluctuation.

There are several other reasons why the "fish balance" can change. For instance, if the aquatic plants become too numerous, the fry and "young of the year" can hide so that the carnivorous species have difficulty in finding food.

Denney (1963) quotes Swingle (1956A) (19) who prepared an aid for biologists to determine whether or not a pond was out of balance. His sampling technique, such as draining or seining the pond, is not feasible for larger lakes or reservoirs. Fish traps, fish nets, shocking of fish etc., could be used to obtain a representative sample of the type, size and condition of the fish. Swingle's description of pond balance is appropriate for reservoirs or lakes:

"In unbalanced ponds, the catch is principally composed of small bluegills of the 3-, 4-, and 5-inch groups...The bass caught are few, but usually larger than 2 pounds".

"In normally balanced ponds, most bluegills caught are above the 6-inch group in size. The average bass caught is from 1- to 2-pounds, but smaller ones and larger ones are also taken. Bluegills are found on beds several times during the Spring and Summer".

"In ponds crowded with bass, almost all bluegills caught are large fish, averaging in excess of 0.3 pounds. They are found on beds several times in the Spring and Summer. The bass caught average less than 1 pound and are in poor condition".

Since aquatic plants are not a problem in Geist Reservoir there is no need for the use of herbicides. Poisoning of fish with rotenone is not feasible for control of fish population. Russian ichthyologists use 0.1 ppm of an organic compound said to be polychlorpinen. Frey (1965) (20).

Restocking Geist Reservoir with predatory fish is the best answer. A larger size such as the "young of the year" instead of "fry" should be used for restocking; these predatory fish would develop more quickly.

Buck (1956) (21), in his paper on the effects of turbidity, covered a study on a series of ponds. The "clear" ponds had a turbidity less than 25, the intermediate ponds had from 25 to 100 turbidity units, and the "turbid" ponds had a turbidity greater than 100 units. Table (21) shows the resulting growth due to variation in turbidity.

Buck (1956) (21) reported a study on two reservoirs. Heyburn Reservoir, which is used for flood control, covers an area of 1,070 acres, has an average depth of 10 feet and a maximum depth of 42 feet. This reservoir had a surface turbidity of from 300 units in March to 51 units in August. The average summer turbidity was 136 units in 1954 and 126 units in 1955. Upper Spavinaw Reservoir, which is a water supply reservoir for the city of Tulsa, Oklahoma, covers 3,192

TABLE (21)

RESULTING GROWTH DUE TO VARIATION IN TURBIDITY

Turbidity Units	<25	25-100	>100
Average weight of fish per acre including Bass, Bluegill and Redear. (Pounds)	161.5	94	29.3
Average growth rate of Bass by weight.* (Multiplication Rate)	6.4	4.0	1.26
Average growth of Bass by length.* (Multiplication Rate)	4.5	3.4	1.5

*Bluegill and Redear fish growth rates are similar to the Bass.

Table (22) shows the effect of turbidity on the young of the year.

TABLE (22)

EFFECT OF TURBIDITY ON YOUNG OF THE YEAR

Turbidity Units	<25	25-100	>100
Bass "Young of the Year" Recovered	7 of 12 ponds	4 of 12 ponds*	0 of 9 ponds
Redear "Young of the Year" Recovered	8 of 9 ponds	9 of 9 ponds	1 of 7 ponds**
Bluegill "Young of the Year" Recovered	All ponds	All ponds	All ponds***

*Greater than 84 turbidity units, no "Young of the Year" was found.

**Greater than 175 turbidity units, no "Young of the Year" was found.

***The "Young of the Year" total weight for a two year period was 10.9 pounds, and the surviving adults weighted only 17.4 pounds. The greatest turbidity at which Bluegills were recorded was 185 units.

acres, with an average depth of 25 feet, and a maximum depth of 92 feet. It has remained reasonably clear since its impoundment in 1952.

Results from these reservoirs paralleled those from farm ponds. All species of fish grew faster in the clear reservoir. Rough fish were more common in the Heyburn Reservoir than in the Spavinaw Reservoir. White crappie grew more slowly in the Heyburn Reservoir, which had greater turbidity than any of the other reservoirs studied. The average second year length for white crappie was 5.0 inches in Heyburn Reservoir, which was at least 3 inches less than the next slowest growth of the other six reservoirs.

The average turbidity in Geist Reservoir, from May to October in 1964 at station 151 was 84 units. The turbidity in section III was found to be 20 to 30 per cent higher than at station 151. Buck (21) found when the turbidity was greater than 84 units, no Bass "Young of the Year" were found. It appears that a large portion of the bass spawning area in section III has been damaged by turbidity.

The spawning areas for bass in section II possibly have not been extensively damaged. It appears that the growth rate for "fry" has been reduced because the turbidity in most of this section is greater than 25 units.

The turbidity values for sections II and III of Geist Reservoir approached or exceeded the amount that Buck (1956) (21) found to have an adverse effect on bluegill, bass and redear fish. The two sections were reported, by the personnel at the marina, as being an area where bass had previously spawned. Section III and part of section II, with turbidity greater than 84 units during the spawning season, are not suitable for the propagation of bass. High turbidities, greater than 100 units, can cause the food supply for fry to be reduced or eliminated. Short food supply will reduce the size or number of forage fish which will reduce the number of carnivarous fish. After the decease in predatory fish, the forage fish will over populate, which leads to stunted fish.

Geist Reservoir's fish population is not in "balance" because of the over propagation of the forage fish.

Usually, the removal of ice from the reservoir is caused by flooding of Fall Creek. After the great influx of water a large Shad kill and a smaller Crappie and Bass kill is observed each year. The turbidities in sections II and III will be as high as 950 units.

The Second Edition of "Water Quality Criteria", publication number 3-A of the California Water Quality Control Board, page 290, lists a number of effects of turbidity on fish and aquatic life. Most of the items on this list have previously been discussed, but quoting one item: "At very high concentrations the particulate matter that produces turbidity can be directly lethal".

A bass fish kill was observed in June 1964 in section II of Geist Reservoir. This fish kill followed the Spring planting of crops and possible spraying of crops with insecticides. Since no autopsy was run to determine the cause of the fish kill, speculation is futile.

Records of the Geist Reservoir marina for calendar year 1964 indicate that there were 2,746 boats that used the ramp facilities and

16,396 trips were made in rental boats. Each boat trip averaged 5 hours and each boat carried an average of 2.5 people per trip. There was a total of 47,850 people fishing from boats. This is equivalent to 239,250 hours spent fishing. The average fish caught by boat fisherman was estimated by marina personnel to weight 0.5 pounds. The marina personnel estimated it took three hours to catch a harvestable fish. The total weight of fish caught from boats was estimated at 39,880 pounds.

The number of bank fisherman were estimated from counts of automobiles present between April 1, to October 31. The average was 58.5 cars per day. It was assumed that the turnover of cars was 2 times each day, which would be an average of 117 cars per day. An estimate of 2 persons per car would equal 234 people per day. The total fishing days in 1964 was 214, which results in an estimate of 50,080 fishermen per year. The marina estimated each bank fisherman spent 4 hours fishing each trip. The average size fish removed from the reservoir was estimated at 0.3 pounds. The time spent to catch a harvestable fish was estimated at 3 hours. The total number of hours people spent in fishing from the banks of the reservoir was 200,300 hours. The estimated number of fish caught was 66,770 fish which represented 20,030 pounds of fish.

An average winter has 50 days available for ice fishing. The total time spent ice fishing was 75,000 hours or 25,000 fish harvested. The average size of the fish taken through the ice is 0.25 pounds or 6,250 pounds of fish removed during the winter.

A summary of total pounds of fish removed from Geist Reservoir in

1964 is shown in Table (23).

TABLE (23)

POUNDS OF FISH REMOVED FROM GEIST RESERVOIR

Type of Fishing	Hours spent Fishing	Pounds of Fish Harvest	Pounds of Fish per acre of Surface Area.
Boat Fishermen	239,250	39,880	22.2
Bank Fishermen	200,300	20,030	11.1
Ice Fishermen	75,000	6,250	3.5
TOTAL	514,550	66,160	36.8

The total expenditure for fishing at Geist Reservoir which includes transportation, food, bait, boat rental, equipment and equipment repairs was estimated to be over $386,000. This estimated amount may be low, since it is based upon a national survey made in 1954 (26).

The pounds of fish taken from the reservoir is based upon an estimate of 3 hours to harvest a fish. This estimate may be conservative, for the Indiana Conservation Commission suggest 1 hour to harvest a fish.

A commerical fish shocking company, worked in a 500 acre area in July 1964 along the shoreline of a portion of sections I and II of the reservoir. Shad and Carp were the only fish harvested and removed from the reservoir. The total weight removed was over 30,000 pounds or equivalent to 60 pounds per surface acre of the reservoir.

Aquatic Plants:

Large aquatic plants are not numerous in Geist Reservoir. The following aquatic plants were found in isolated shallow areas:

1.	Duckweed	Lemna
2.	American Lotus	Nelumbo lutera
3.	Pondweed	Potamogeton americanus
4.	Cattails	Typha latifolia
5.	Unidentified	

Plankton samples were collected at mid-depth in areas where the water was less than 10 feet deep. In depths greater than 10 feet, the samples were taken at 5 feet unless additional samples were taken. The samples were preserved with formalin and later concentrated by the Sedgwick-Rafter method. In this report, algae that has been concentrated are called "Net Algae." There has been no attempt made to identify or to count nannoplankton, zooplankton or benthic algae. The method employed for making counts of algal organisms was by use of a Sedgwick-Rafter cell and by counting either strip, field, or the whole cell. Each different organism was measured. The volume of each cell or unit (part of a cell or colony) was calculated from the measurements. All algal results are reported as ppm (volume).

A percentage value was calculated for the euphotic zone of each section based upon the total for the reservoir. As a rule, section I represents approximately 71 per cent, section II approximately 24 per cent and section III represents approximately 5 per cent of the euphotic zone of Geist Reservoir.

In 1963, from the middle of April to the middle of October, approximately 2,830,700 pounds (dry weight) of algae or 1,572 pounds per acre of surface area were produced in the reservoir. The monthly averages of dissolved oxygen did not exceed 100 per cent saturation when the algae measured less than 160 pounds (dry weight) per acre per month. The value of 160 pounds is correct from April to November except when the inorganic nitrogen value exceeds 0.30 ppm and the N:P ratio was greater than 7:1 and less than 47:1.

The greatest average monthly algal mass for 1963, was 123.2 ppm, which occurred in June at station 152; 116.5 ppm of the 123.2 ppm were pigmented flagellates. The greatest number found in a given sample was 427.9 ppm of which 416.6 ppm were pigmented flagellates. This large number was found on June 17, 1963 at station 152.

The phytoplankton growth rate of April 1963, was stimulated by the increase in nutrients carried in by high inflows of March 1963. This accelerated growth was observed from April through June, but in July a "die away" or reduction in the algal mass occurred. The algal mass was 740 pounds (dry weight) per acre in June and was reduced to 150 pounds (dry weight) per acre in July. The reduction in the algae appeared to be caused by the reduction in nutrients. The ability of an organism to carry on its metabolism and reproduce the species is limited by the nutrients present if the other ecological factors are favorable. The above statement is an over simplified explanation of Liebig's "Law of the Minimum." (5e)

A drought began in August 1963, that extended into 1964. The possible lack of nutrients caused a further reduction of algae to only 100 pounds (dry weight) per acre for August. Temporary increases in inorganic nitrogen and soluble phosphorus during this drought, produced periods of supersaturation, and permitted the algae to store nutrients (25). The utilization of the stored nutrient prolonged the period of high photosynthetic activity. A number of attempts to run a diurnal to measure supersaturation of dissolved oxygen in the afternoon ended in failure, because photosynthesis was not being conducted at a rate that would produce dissolved oxygen values equal to 100 per cent or more.

The algal mass increased from 100 pounds per acre in August 1963, to 150 pounds per acre in September and to 160 pounds per acre in October. The inorganic nitrogen values remained low, less than 0.20 ppm, in section I. This increase in the algal mass is not understood at this time.

In 1964, from the middle of April to the middle of October, approximately 2,740,000 pounds (dry weight) of algae or 1,522 pounds per acre of surface area was produced in the reservoir. The greatest production of algae, 470 pounds per acre, occurred in July. The predominate group was the green algae and green pigmented flagellates. All months, except April and October 1964 during this 7 month period had supersaturated values in the afternoon.

Table (24), shows the algae present in decending order at each station.

TABLE (24)*

OCCURRENCE OF ALGAE IN GEIST RESERVOIR, 1962-65

Month	Station 111	Station 151	Station 152	Station 191
Jan.	27, 31	23	26, 21	42, 26
Feb.	23	23	23, 21, 24	24, 23, 26
March	23, 47	23	23, 32, 42	32, 23, 21
April	22, 21, 27	22, 27, 21	21, 33, 42	21, 42, 33
May	23, 24, 29	21, 23, 49	21, 23, 40	23, 40, 53
June	40, 23	40, 26, 42	40, 49, 46	40, 48, 42
July	30, 11	30, 40, 33	11, 54, 30	53, 21, 26
Aug.	30, 40, 23	21, 30, 42	21, 26, 34	21, 40, 39
Sept.	39, 23, 30	40, 42, 21	40, 42, 39	40, 11, 22
Oct.	34, 42, 23	41, 40, 11	39, 26, 40	22, 40, 46
Nov.	39, 23, 44	23, 26	26, 23, 21	26, 23
Dec.	22, 26	23, 26	23, 21	27, 21, 31

* Numbers correspond to the listing of algal organisms in Table (25).

TABLE (25)

ALGAE IDENTIFIED IN GEIST RESERVOIR, 1962-1965

Green (Nonmotile Chlorophyceae)

1. Actinastrum Hantzschii
2. Ankistrodesmus falcatus
3. Chlorella ellipsoidea
4. Closteriopsis longissima
5. Crucigenia rectangularis
6. Crucigenia tetrapedia
7. Coelastrum sp
8. Dictyosphaerium pulchellum
9. Micractinium pusillum
10. Micrasterias sp
11. Pediastrum simplex
12. Scenedesmus acuminatus
13. Scenedesmus bijuga
14. Scenedesmus dimorphus
15. Scenedesmus quadricauda
16. Tetraedron sp

Green algae found in Reservoir but not in algal counts.

17. Rhizcolonium sp
18. Spirogyra sp

Diatom (Bacillariophyceae)

19. Amphora Ovalis
20. Asterionella sp
21. Cyclotella sp
22. Cymbella sp
23. Diatoma sp
24. Fragilaria sp
25. Gomphonema sp
26. Melosira sp
27. Navicula sp
28. Nitzschia sp
29. Pinnularia sp
30. Stephanodiscus sp
31. Synedra Spulchella
32. Synedra Ulna
33. Tabellaria sp

Blue-Green (Myxophyceae)

34. Anabaena sp
35. Anacystis sp

Blue-Green (Myxophyceae) (cont.)

36. Lyngbya sp
37. Merismopedia sp
38. Oscillatoria sp
39. Oscillatoria (Type)

Pigmented Flagellate

(a) Euglena (Euglenoplyceae)

40. Euglena acus
41. Euglena proxima
42. Euglena sp
43. Phacus longicauda
44. Phacus sp
45. Trachelomonas sp

(b) Dinophyceae

46. Ceratium cornutum
47. Ceratium hirundinella
48. Gymnodinium sp
49. Peridinium Bipes

(c) Crytophyceae

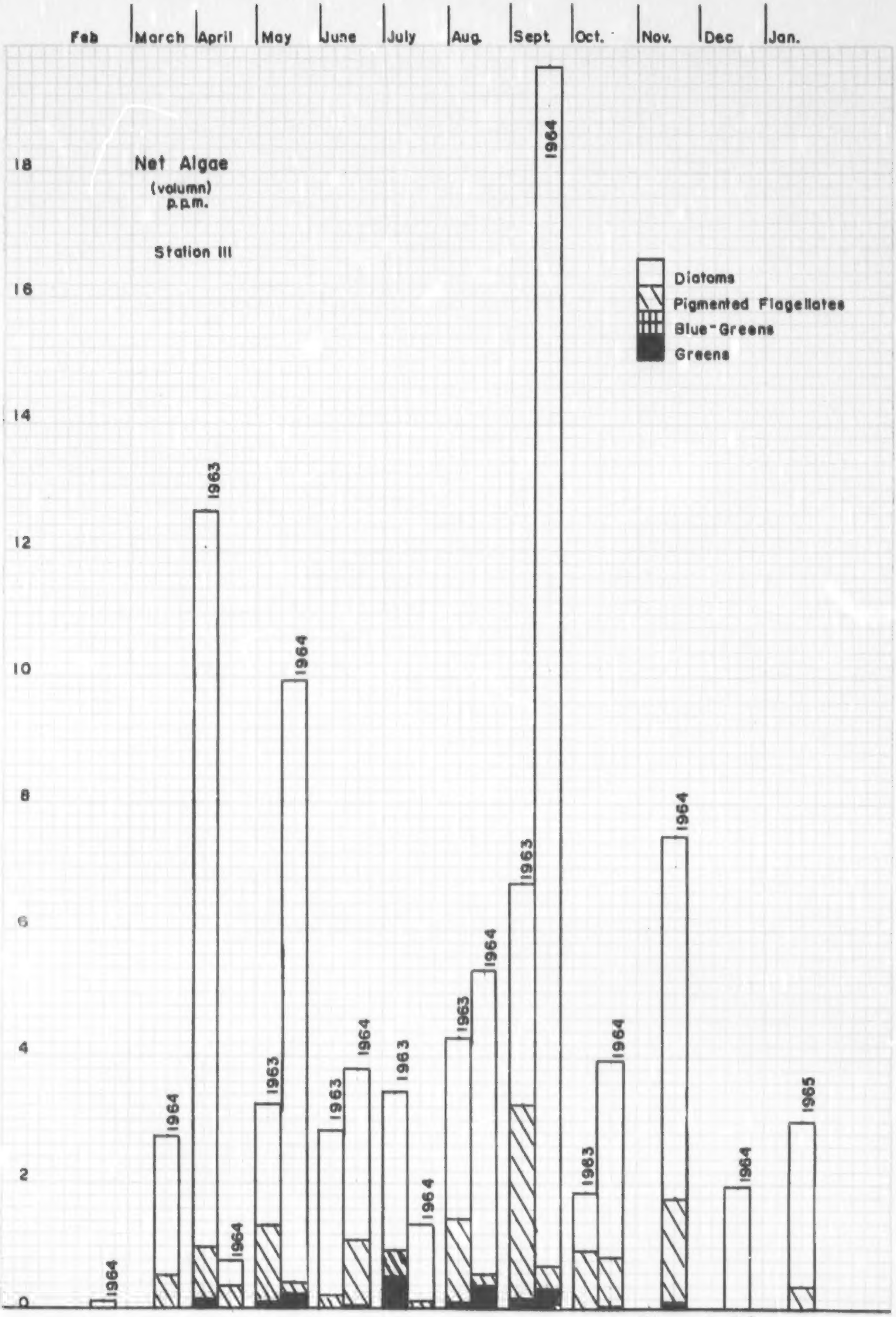
50. Cryptomonas sp

(d) Chrysophyceae

51. Dinobryon sociale

(e) Chlorophyceae

52. Chlamydomonas globosa
53. Panderina sp
54. Platydorina Caudata

Feb
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec
Jan.
Net Algae
(volumn)
p.p.m.
Station III
Diatoms
Pigmented Flagellates
Blue-Greens
Greens
0
2
4
6
8
10
12
14
16
18
1964
1964
1963
1964
1963
1964
1963
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1963
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1963
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1963
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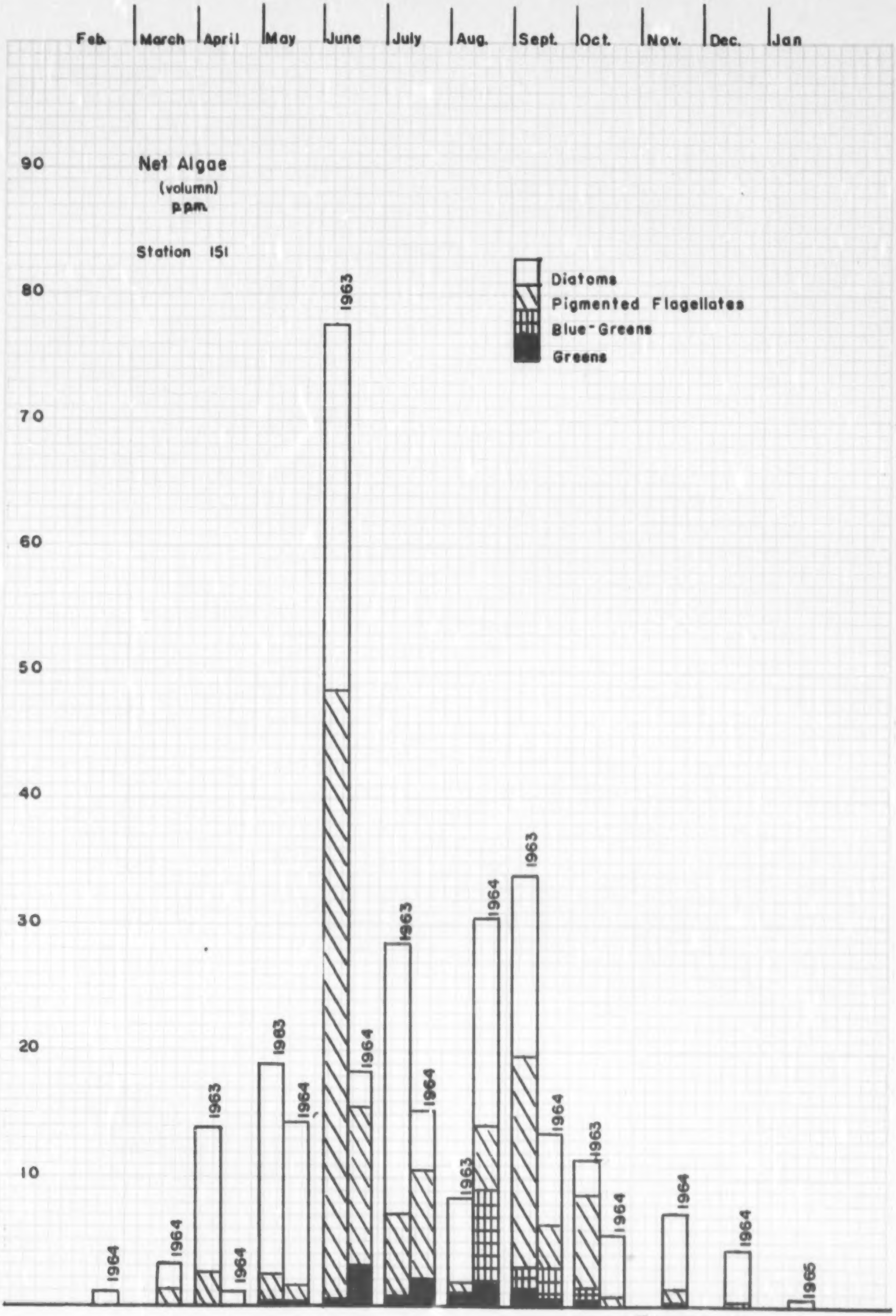
1964
1964
1965

Figure 16



Feb.
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan
Net Algae
(volumn)
p.p.m.
Station 151
Diatoms
Pigmented Flagellates
Blue-Greens
Greens
90
80
70
60
50
40
30
20
10
1963
1964
1965

Figure 17

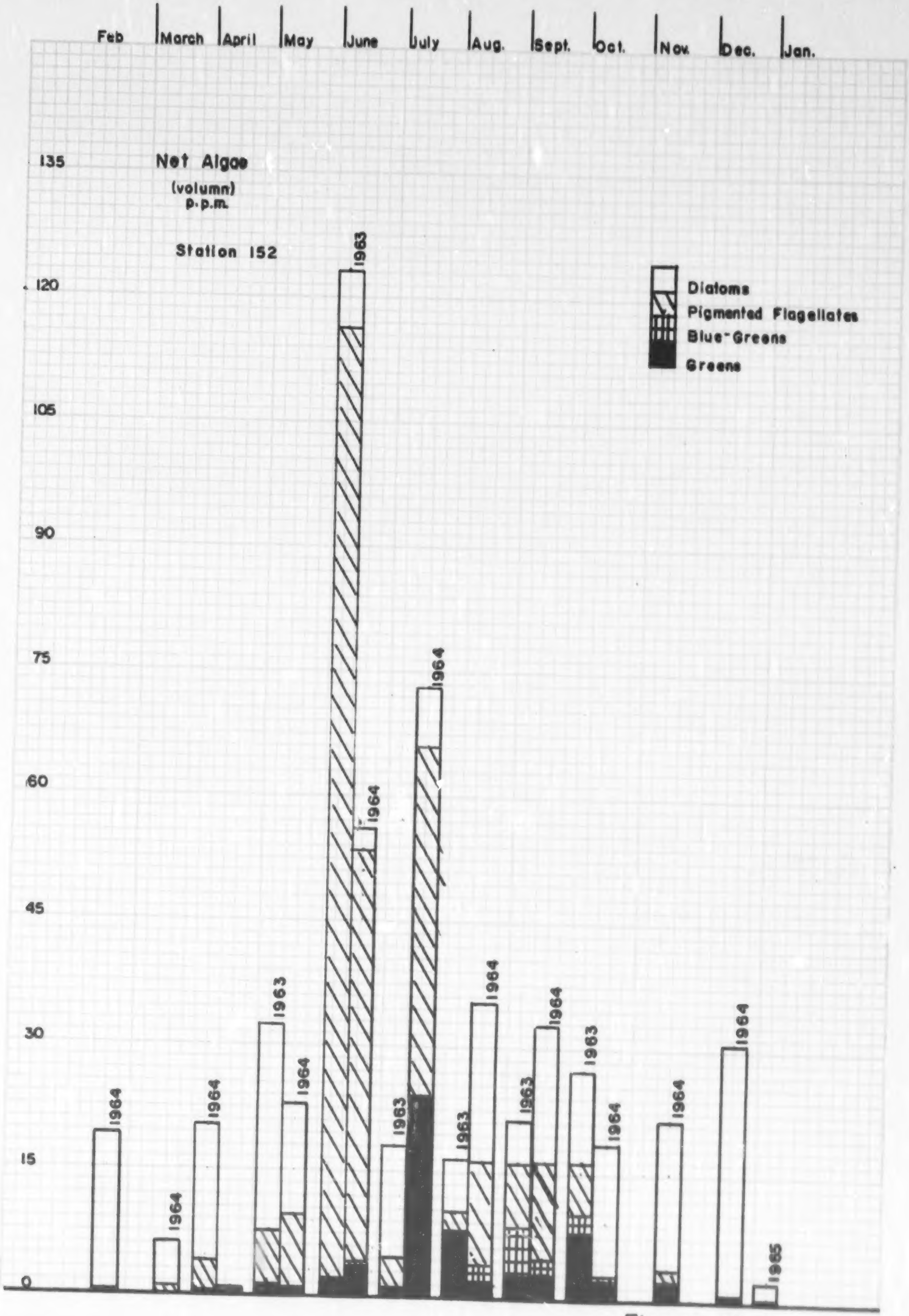

Feb
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Net Algae
(volumn)
p.p.m.
Station 152
135
120
105
90
75
60
45
30
15
0
Diatoms
Pigmented Flagellates
Blue-Greens
Greens
1963
1964
1965

Figure 18

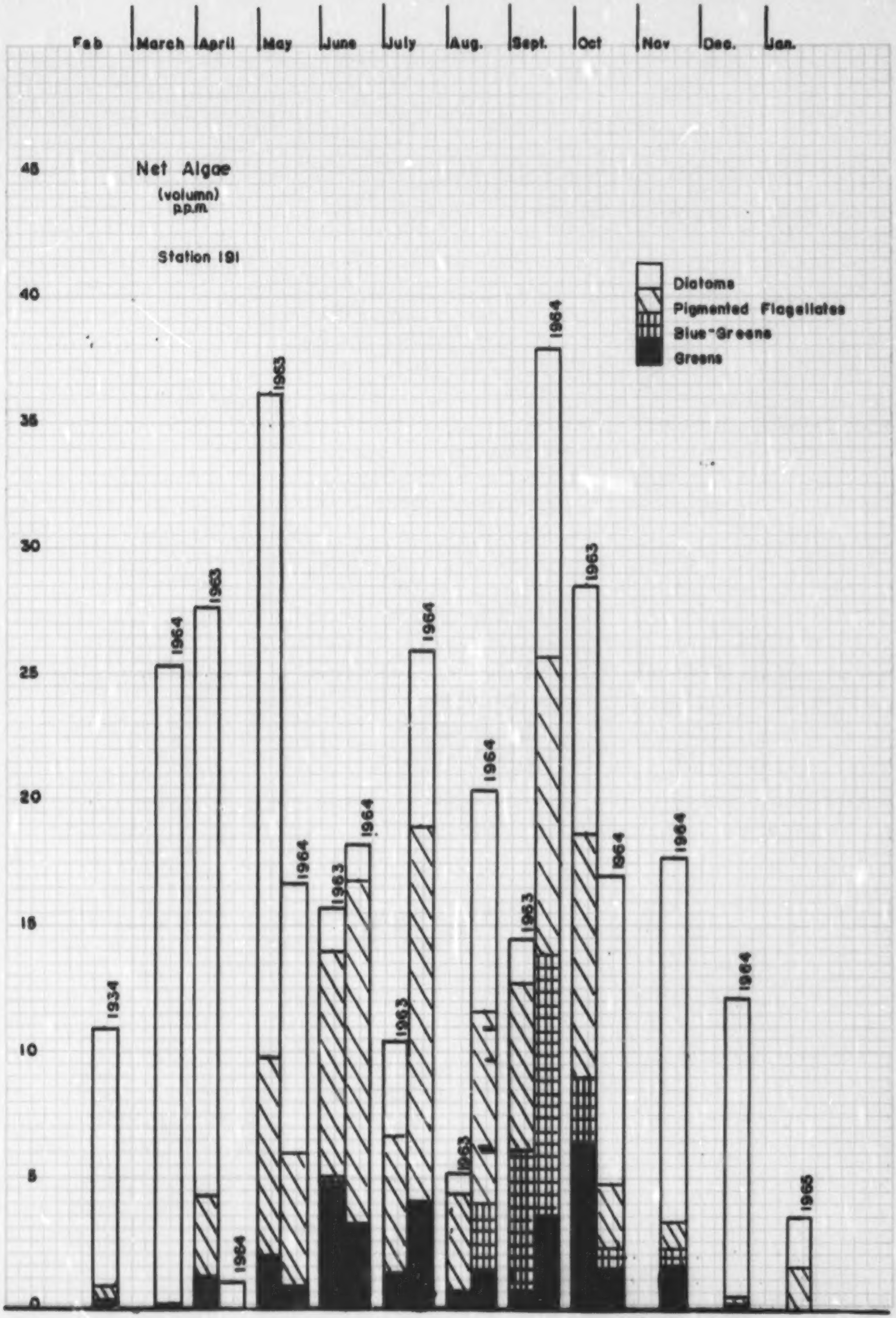
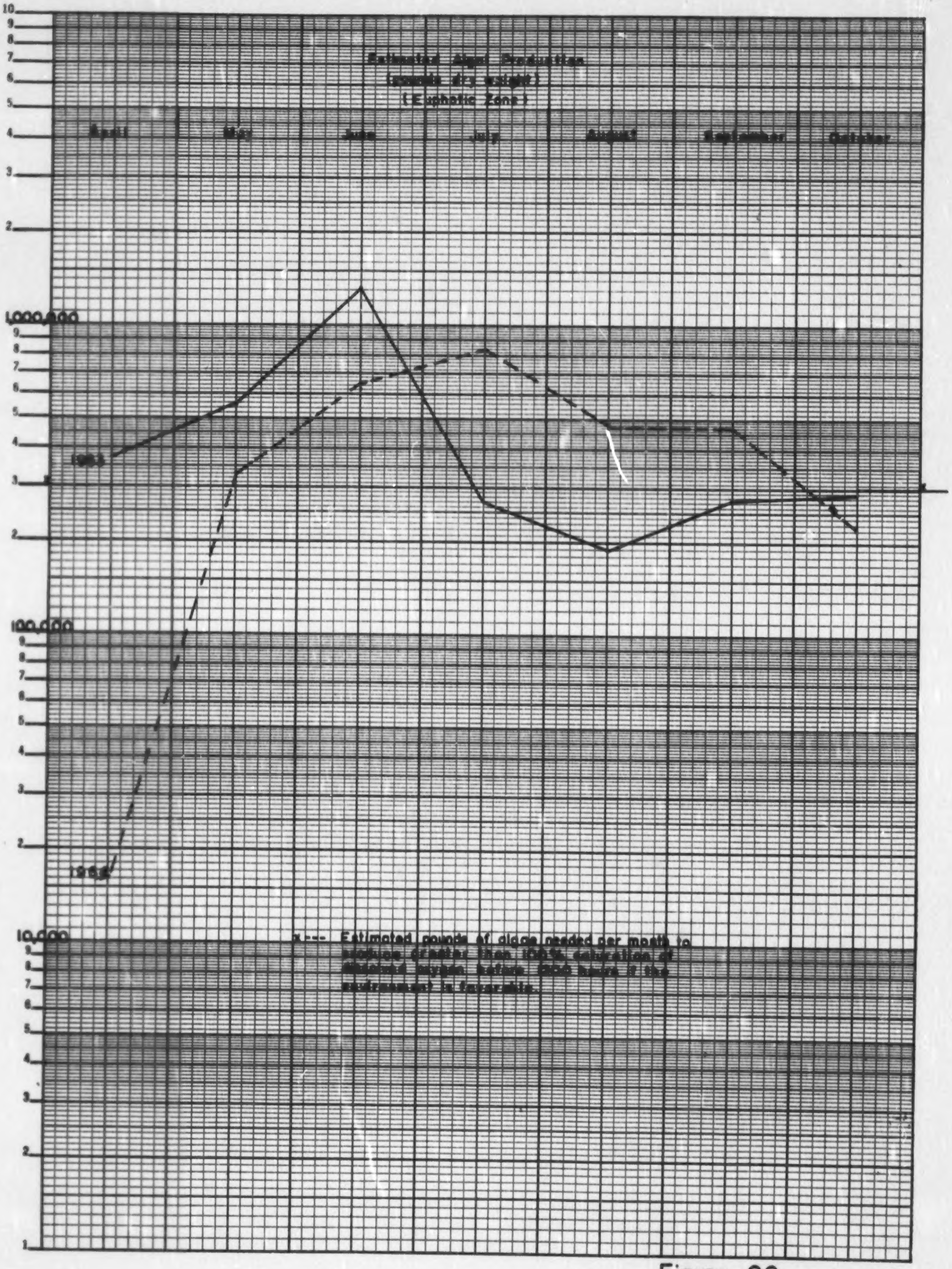

Feb
March
April
May
June
July
Aug.
Sept.
Oct
Nov
Dec.
Jan.
Net Algae
(volumn)
p.p.m.
Station 191
Diatoms
Pigmented Flagellates
Blue-Greens
Greens
45
40
35
30
25
20
15
10
5
0
1934
1964
1963
1964
1963
1964
1963
1964
1963
1964
1963
1964
1963
1964
1963
1964
1964
1964
1965

Figure 19



SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 20

SURVEY OF GEIST RESERVOIR BENTHOS*
OCTOBER, 1964

INTRODUCTION

Bottom samples were collected during the week of October 20, 1964, from 29 stations on 8 transections across Geist Reservoir to determine the fall standing crop of benthos (Figure 21). These stations and transections, excluding those along Transect 8, are essentially identical to those sampled during the week of October 28, 1963. Stations along transect Number 8 were not sampled during the 1963 survey. Samples were obtained with an Ekman dredge, washed and strained through a U. S. Standard No. 30 sieve, preserved, and transported to SEC for organism identification (Appendix I) and enumeration.

The water level in Geist Reservoir was near 6-feet below normal at the time of the October, 1964 survey. The reduced level exposed mud flats in shallow bays and upstream reaches of the reservoir, effected concentration of bottom organisms into submerged areas of the basin, and limited sampling to the lower and middle basins as delineated by roads in Figure 21.

---

* Report by R. Keith Stewart, Biologist, Technical Advisory and Investigations Section, WS&PC, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

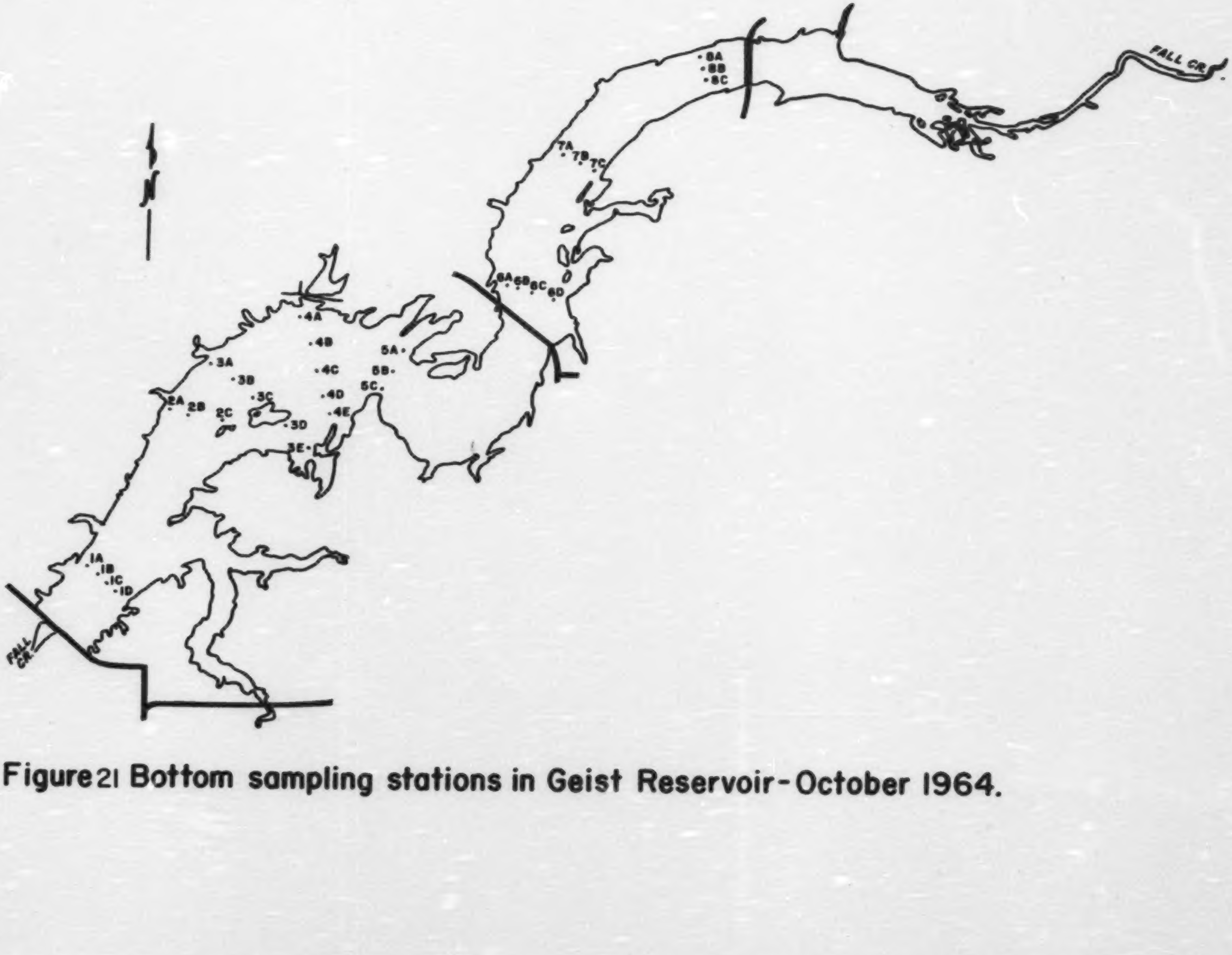

N
FALL CR.
8A
8B
8C
7A
7B
7C
6A
6B
6C
6D
5A
5B
5C
4A
4B
4C
4D
4E
3A
3B
3C
3D
3E
2A
2B
2C
1A
1B
1C
1D
FALL CR.

Figure 21 Bottom sampling stations in Geist Reservoir-October 1964.

RESULTS

Comparisons of the density of organisms from station to station show great variation in the benthos standing crop (Table 26 and Figure 22). The benthic population ranged from 220 to 1,180 organisms per square foot in the middle basin. Sludgeworms predominated the benthos and attained populations near 900 individuals per square foot. Such populations show that the middle basin serves as a settling area for nutrient materials which flow into the reservoir and ultimately effect a food supply for these organisms. The shallow depth of this basin limited development of larval phantom midge populations (Chaoborus punctipennis and Chaoborus sp.) except at one location where 1,120 per square foot were found. One alderfly (Sialis sp.) was collected at Station 6D. This station contained silty bottom materials mixed with small stones and could support only a limited number of such organisms.

The benthic population in the lower reservoir ranged to a maximum of 2,612 organisms per square foot and, like that in the middle basin, was predominately sludgeworms. Sludgeworm and phantom midge populations were significantly higher in the lower basin than in the upper basin. Higher phantom midge populations in the lower basin are attributed to deeper water which attains a maximum depth near 20-feet. The abundance of sludgeworms in the lower basin, particularly in the upper reaches, suggests

Table 26 - Geist Reservoir--Bottom Organisms Per Square Foot
October, 1964

Station	Phantom Midge	Bloodworm	Sludgeworm	Other	Total
1A	92	40	92	4	228
1B	288	12	12	0	312
1C	48	16	0	0	64
1D	560	16	0	4	580
2A	12	196	128	4	340
2B	336	76	416	0	828
2C	36	16	160	12	224
3A	684	156	232	44	1116
3B	1464	124	336	12	1936
3C	-	-	-	-	*
3D	16	80	68	160	324
3E	244	8	696	88	1036
4A	120	504	1456	40	2120
4B	480	164	1904	64	2612
4C	132	80	1104	32	1348
4D	352	8	560	32	952
4E	16	96	288	68	468
5A	540	4	968	16	1528
5B	196	16	1376	32	1620
5C	348	8	92	12	464

Table 26 (Cont'd)

Station	Phantom Midge	Bloodworm	Sludgeworm	Other	Total
6A	64	12	288	24	388
6B	60	12	172	44	288
6C	0	52	952	0	1004
6D	1120	24	8	28	1180
7A	52	0	868	12	932
7B	148	0	344	12	504
7C	32	0	640	24	696
8A	20	0	304	36	360
8B	56	0	800	72	928
8C	0	12	208	0	220

* No organisms sampled due to gravel and sand bottom.

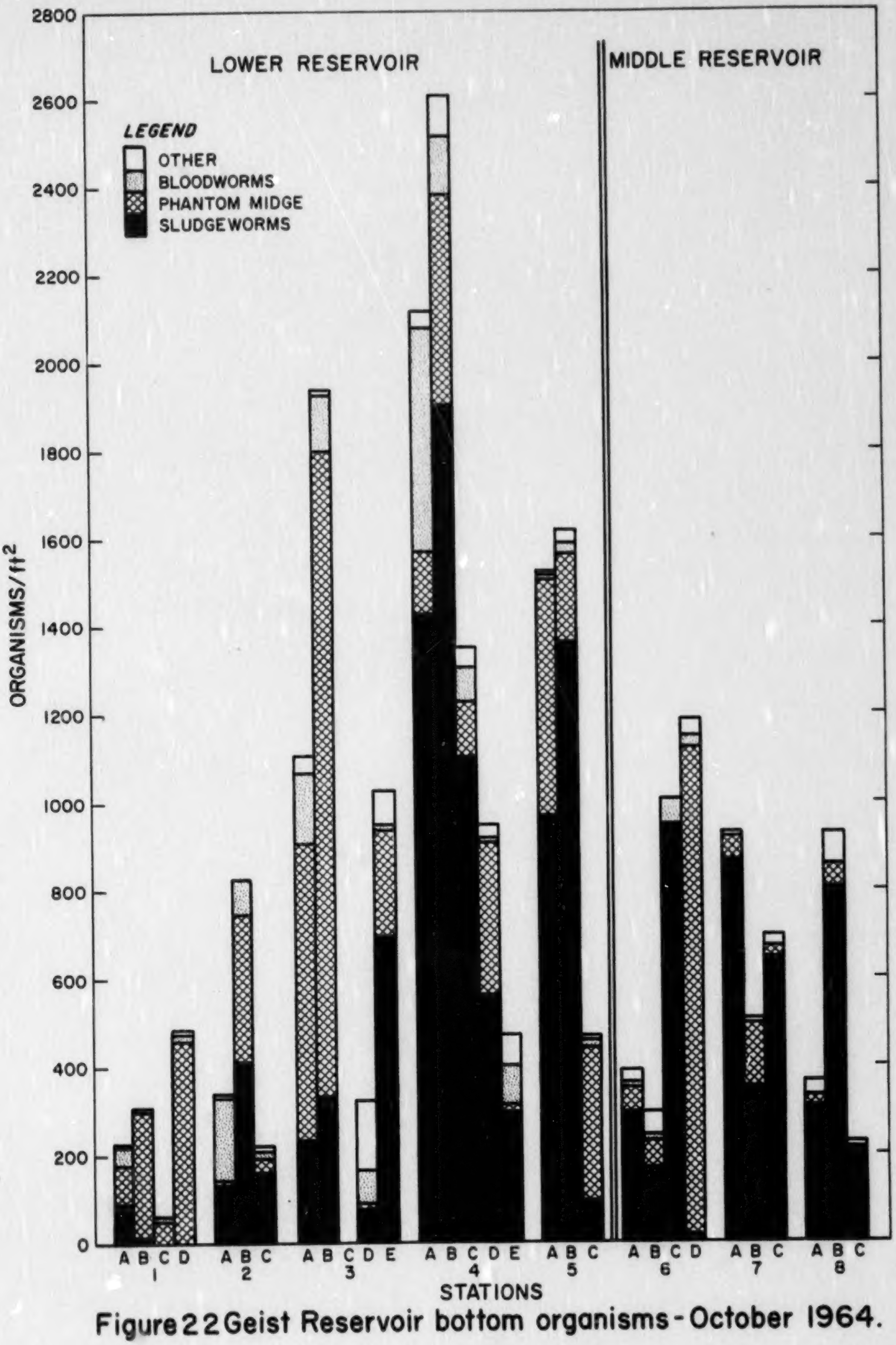


Figure 22 Geist Reservoir bottom organisms - October 1964.

that rich organic materials comprising food for these organisms are concentrated in an area circumscribed by Transects 4 and 5. The bottom environment in this area was not suitable to support high numbers of larval phantom midges and bloodworms (*Tendipes tentans* - *plumosus* and *Tendipes* *spp*.) and facilitated development of dense sludgeworm populations near 1,900 individuals per square foot. Phantom midges and bloodworms generally predominated in the benthos community in other areas of the lower basin where conditions were more favorable to such organisms.

Personnel of the Indiana Water Quality Recreation Study Project conducted another benthos survey of Geist Reservoir during July 16-23, 1964, enumerated organisms in the samples, and later sent them to SEC for identification and data analysis. The reservoir was full during July, and samples were collected from each of the three basins. Results of the July survey compared to the October survey are as follows:

Kind of Organisms	% of Samples with Organisms		Number Per Square Foot			
			Max		Mean	
	July	Oct.	July	Oct.	July	Oct.
Sludgeworms	76	93	400	1904	102	499
Phantom Midges	84	93	620	1464	179	259
Bloodworms	54	83	42	156	7	59
Other	46	83	67	160	10	30
Total Organisms			674	2612	298	850

Direct station comparisons were not possible because many transects sampled in October were not sampled in July and certain data for July were not available. The comparison above, however, suggests a much larger standing crop in October and an especially larger population of sludgeworms.

DISCUSSION

Twenty-four stations along seven transects at Geist Reservoir were sampled during the week of October 28, 1963, and the results were reported by Mackenthun in the Indiana Water Quality Recreation Study Progress Report for the 1963 Recreation Season, dated July, 1964. Results of 1963 compared to the October, 1964 benthic study are summarized as follows:

Kind of Organisms	% of Samples With Organisms		Number Per Square Foot Max		Number Per Square Foot Mean	
	1963	1964	1963	1964	1963	1964
Sludgeworms	84	93	980	1904	174	499
Phantom Midges	88	93	480	1464	133	259
Bloodworms	79	83	96	156	30	59
Other	24	83	8	160	1	30
Total Organisms			984	2612	338	850

Station and transect comparisons of these surveys showed a greater total standing crop in the fall of 1964, a significant increase in the benthos of the lower basin, and higher sludgeworm populations in the upper reach of the lower basin than at a similar time in 1963 (Figures 23, 24 and 25). The total standing crop in October, 1964 represented slightly more than a threefold increase above that in October, 1963 (Figure 25) and suggests enrichment of the reservoir.

Mackenthun reviewed certain benthos literature in the Indiana Water Quality Recreation Study Progress Report for the 1963 Recreation Season and found the population of bottom organisms in Geist Reservoir numerically comparable to those in other lakes and reservoirs with moderately productive waters. The results of the October, 1964 survey support that conclusion and show an annual fluctuation of benthos populations suggestive of annual variation in over-all reservoir fertility. The middle basin and upper reaches of the lower basin are especially productive, particularly regarding sludgeworms, while the lower reach of the lower basin supports a more balanced population characteristic of shallow fertile water bodies.

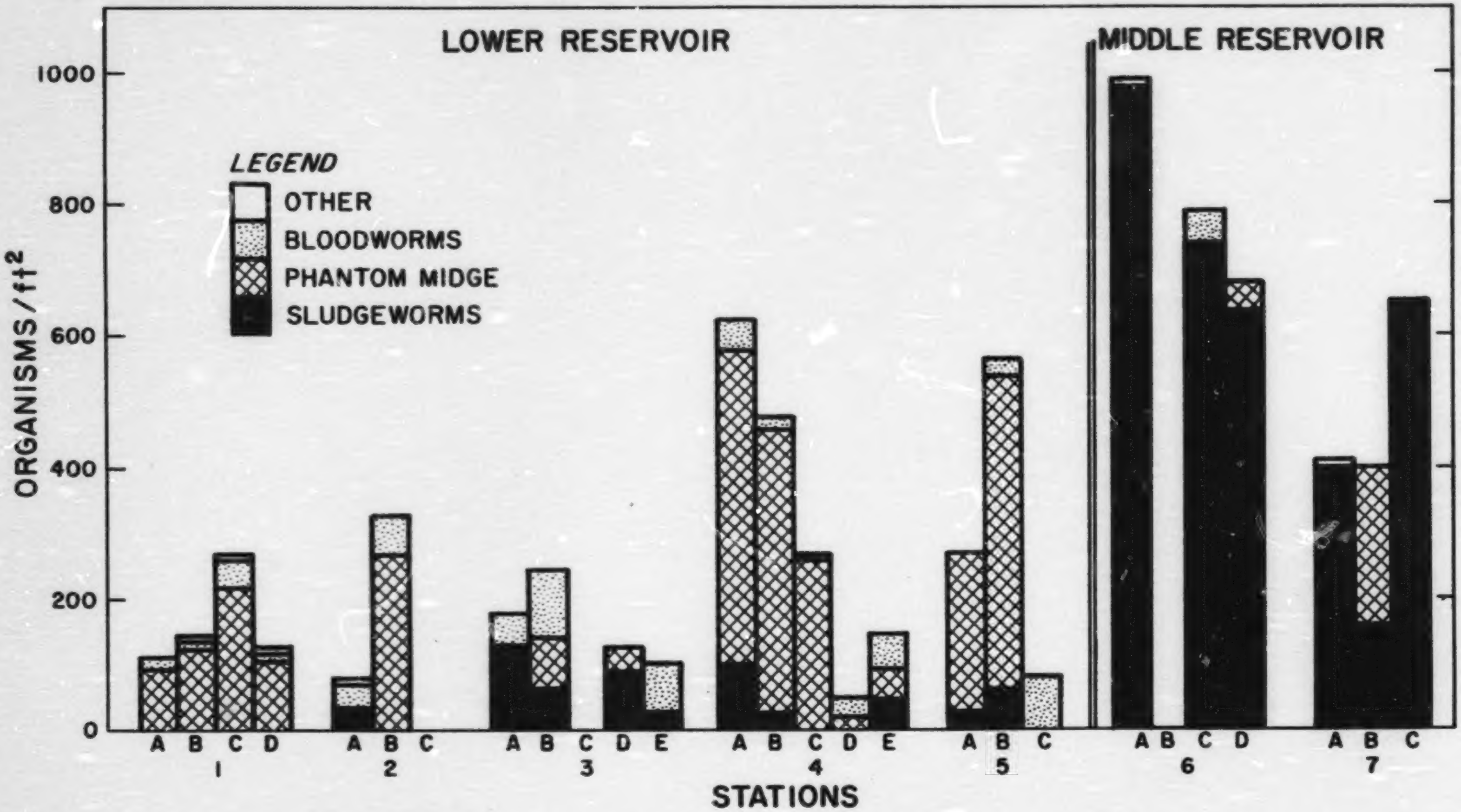


Figure 23 Geist Reservoir bottom organisms - October 1963.

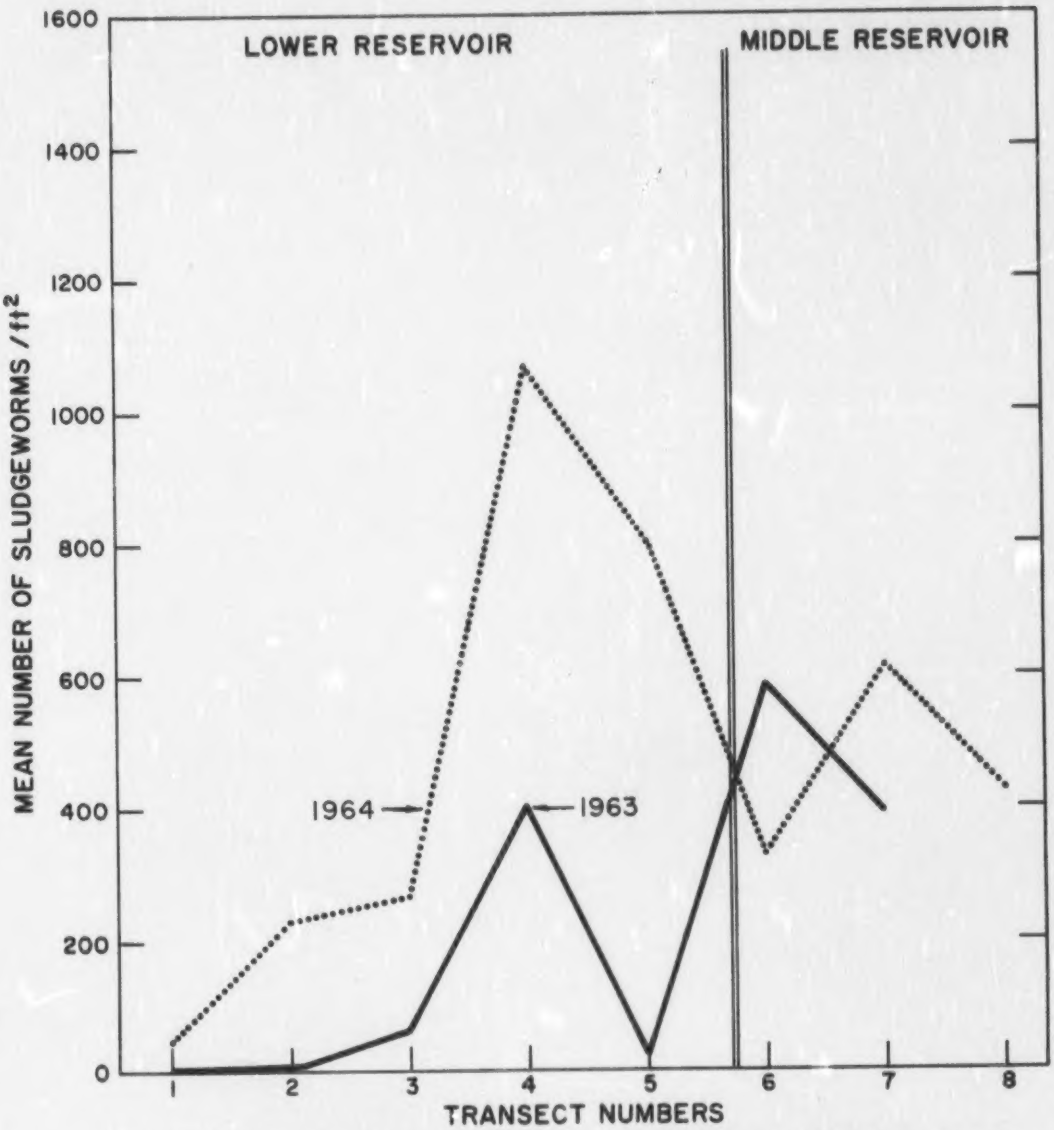


Figure 24 Comparison of average sludgeworm standing crops along transects at Geist Reservoir – October 1963 and October 1964.

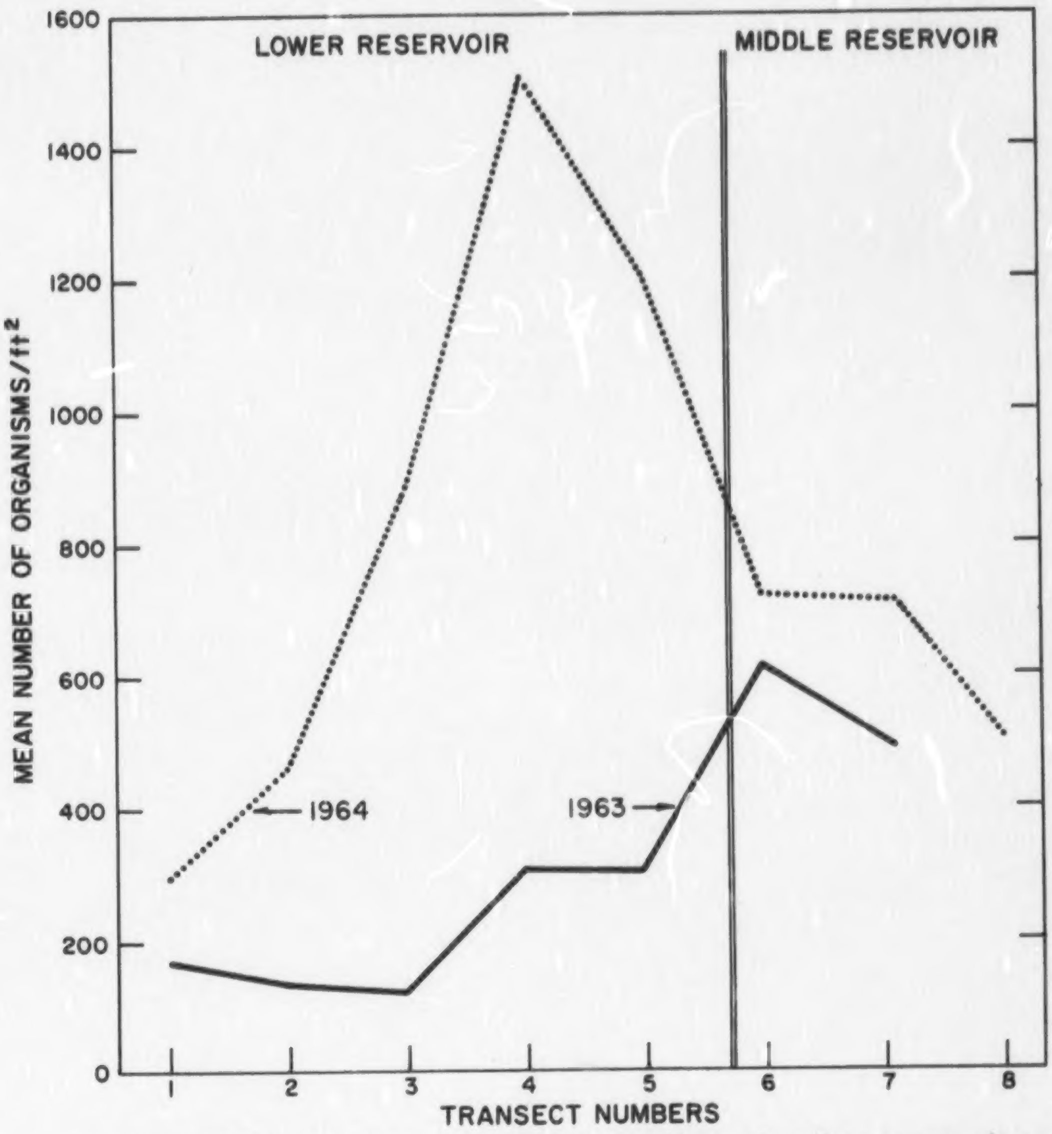


Figure 25 Comparison of average benthos standing crops along transects at Geist Reservoir - October 1963 and October 1964.

APPENDIX I
Geist Reservoir--Kinds of Bottom Organisms Sampled
October, 1964*

Tendipedidae - Bloodworms

- *Tendipes tentans-plumosus*
- *Tendipes spp.* (thumni group)

Tendipedidae - Other Tendipedinae

- *Glyptotendipes senilis*
- *Polypedilium scalaenum*
- *Cryptochironomus spp.*
- *Calopsectra sp.* (Rheotanytarsus group)
- *Pseudochironomus fulviventrus*
- *Tanytarsus fuscicornis* (?)

Tendipedidae - Pelopiinae

- *Coelotanypus concinnus*
- *Procladius culiciformes*
- *Procladius adumbratus* (?)
- *Procladius sp.*
- *Pelopia stellata*
- *Pelopia species B* (Johannsen)

Ceratopogonidae - Biting Midges

- *Palpomyia spp.*

Culicidae - Chaoborinae - Phantom Midges

- *Chaoborus punctipennis*
- *Chaoborus sp.*

Megaloptera - alderflies

- *Sialis sp.*

---

* Excluding sludgeworms (Oligochaeta)

Bacteriological:

Coliform, Fecal Coliform and Enterococcus tests were conducted, 1962-1965, to measure the bacterial quality of the water in Geist Reservoir. The membrane filter technique was used for all three tests. Coliform and Enterococcus test procedures are given in "Standard Methods." Fecal Coliform media and technique for the membrane filter method was developed by Geldreich et al (22). Table (27) gives the maximum, median, and minimum values for the four major sampling stations of Geist Reservoir. The other two sampling stations were on wet weather tributaries that only flowed for a short duration.

TABLE (27)

NUMBER PER 100 ml

Sta		Coliform	Fecal Coliform	Enterococcus
111	Maximum	95,000	12,250	2,550
	Median	4,200	780	60
	Minimum	100	44	15
151	Maximum	6,450	1,140	150
	Median	790	300	14
	Minimum	2	2	2
152	Maximum	7,800	6,500	228
	Median	530	200	7
	Minimum	2	2	2
191	Maximum	1,660	1,320	328
	Median	38	14	5
	Minimum	2	2	2

Table (28) gives the per cent of individual samples at stations 111, 151, 152 and 191 of total coliform that are grouped in 0-50 per

100-ml, 50-5,000 per 100-ml and 5,000 or greater per 100-ml.

The U. S. Public Health Service has made recommendations for treatment of raw water for a potable water supply, (23) which can be briefly summarized as follows: "If a water is to be treated by simple chlorination, the average coliform density should not exceed 50 per 100-ml any month, and if treatment is to conventional rapid sand filtration with continuous chlorination, the coliform density should not average more than 5,000 per 100-ml during any month."

TABLE (28)

PER CENT COLIFORM DISTRIBUTION

Total Coliform Group	Sampling Stations 111	151	152	191
0-50 per 100-ml	1%	35%	73%	87%
50-5,000 per 100-ml	64%	62%	26%	13%
5,000 or greater than per 100-ml	35%	3%	1%	0%

At the discharge station, 191, (Table (28)), 87 per cent of the samples taken would indicate that only simple chlorination would be needed. Based on the median results, treatment by simple chlorination of total coliform is all that would be needed, but during great inflow, usually March or April, when the retention time in the reservoir is reduced to only two days, the most effective type of treatment is needed.

Geldreich et al (24) states that if a ratio between Fecal Coliform and Enterococcus is greater than 2:1, then the source of bacteria is usually from domestic sewage. All the median results for Fecal Coliform and Enterococcus, Table (27), would indicate the source of pollution is from domestic sewage.

The importance of the time of passage from sampling station 111 to 191 is evident in the percentage reduction of the bacteria. The per cent reduction for the three types of bacteria tested were: Total Coliform, 99.1; Fecal Coliform, 98.2; and Enterococcus 91.7. Time of passage during a deluge period is greatly reduced. The high flows that flush out the stream bed above the reservoir increase the bacteria counts in Geist Reservoir to the maximum shown in Table (27).

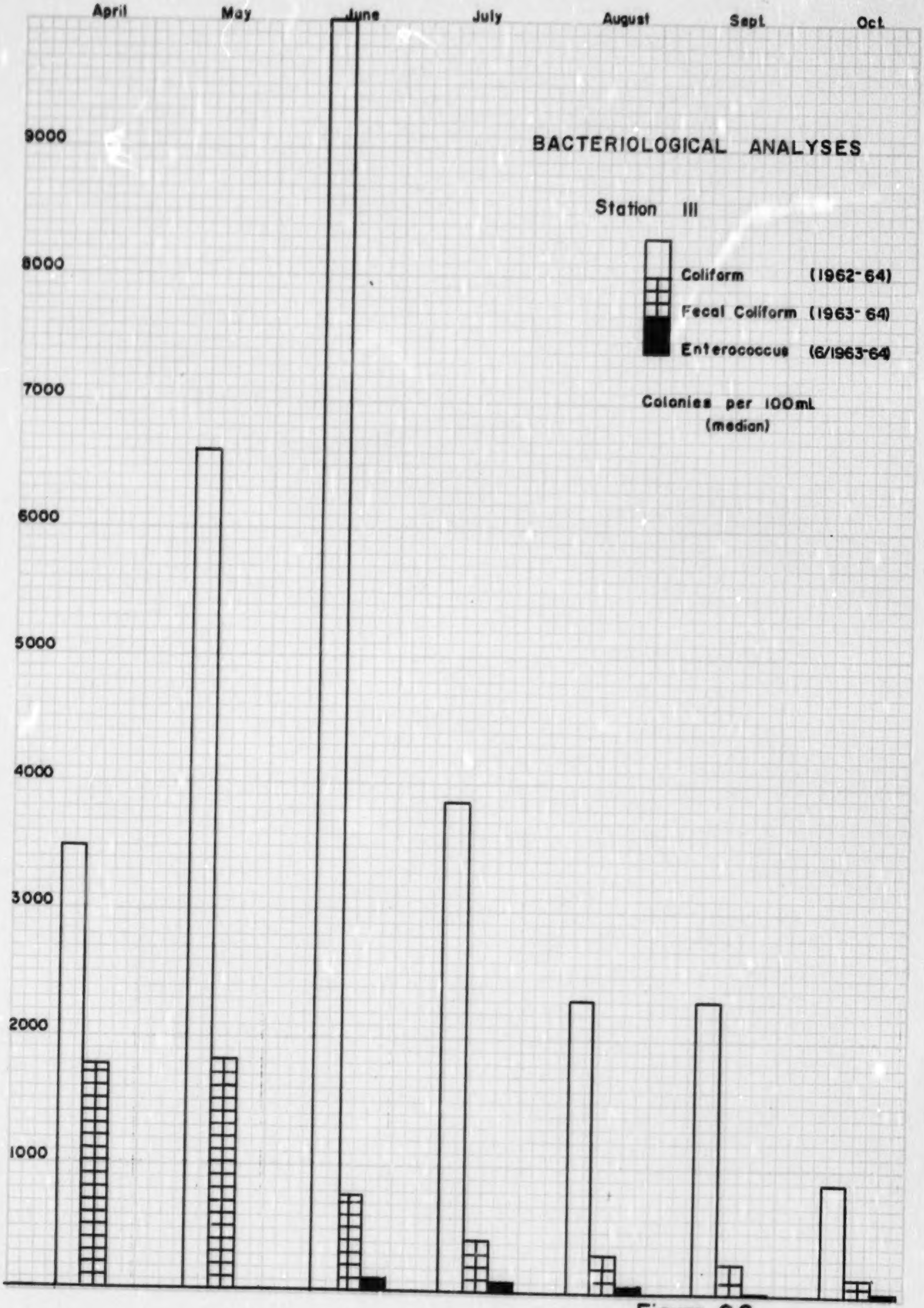

April
May
June
July
August
Sept.
Oct.
9000
8000
7000
6000
5000
4000
3000
2000
1000
BACTERIOLOGICAL ANALYSES
Station III
Coliform (1962-64)
Fecal Coliform (1963-64)
Enterococcus (6/1963-64)
Colonies per 100ml.
(median)

Figure 26

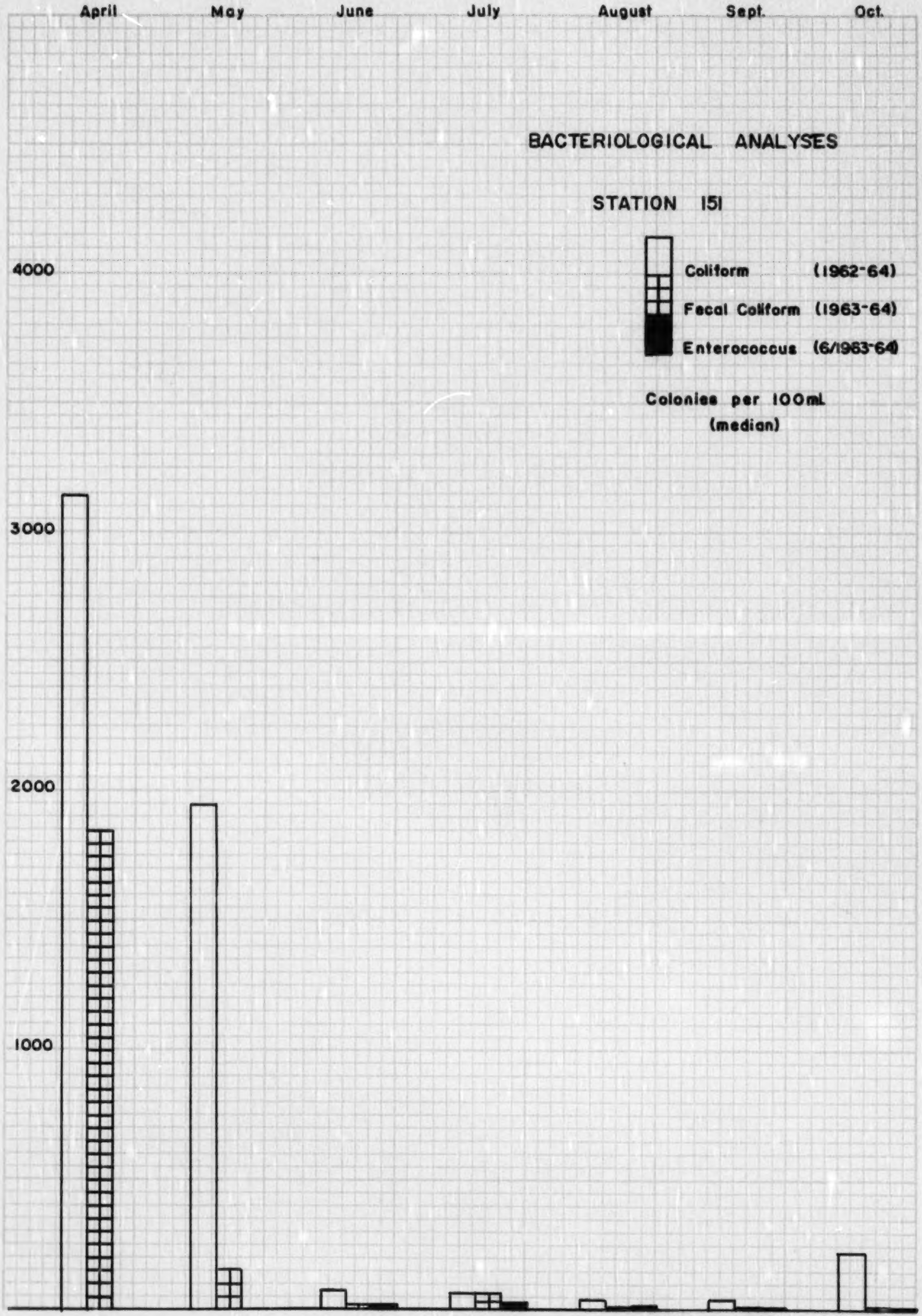

April
May
June
July
August
Sept.
Oct.
BACTERIOLOGICAL ANALYSES
STATION 151
Coliform (1962-64)
Fecal Coliform (1963-64)
Enterococcus (6/1963-64)
Colonies per 100ml.
(median)
4000
3000
2000
1000

Figure 27

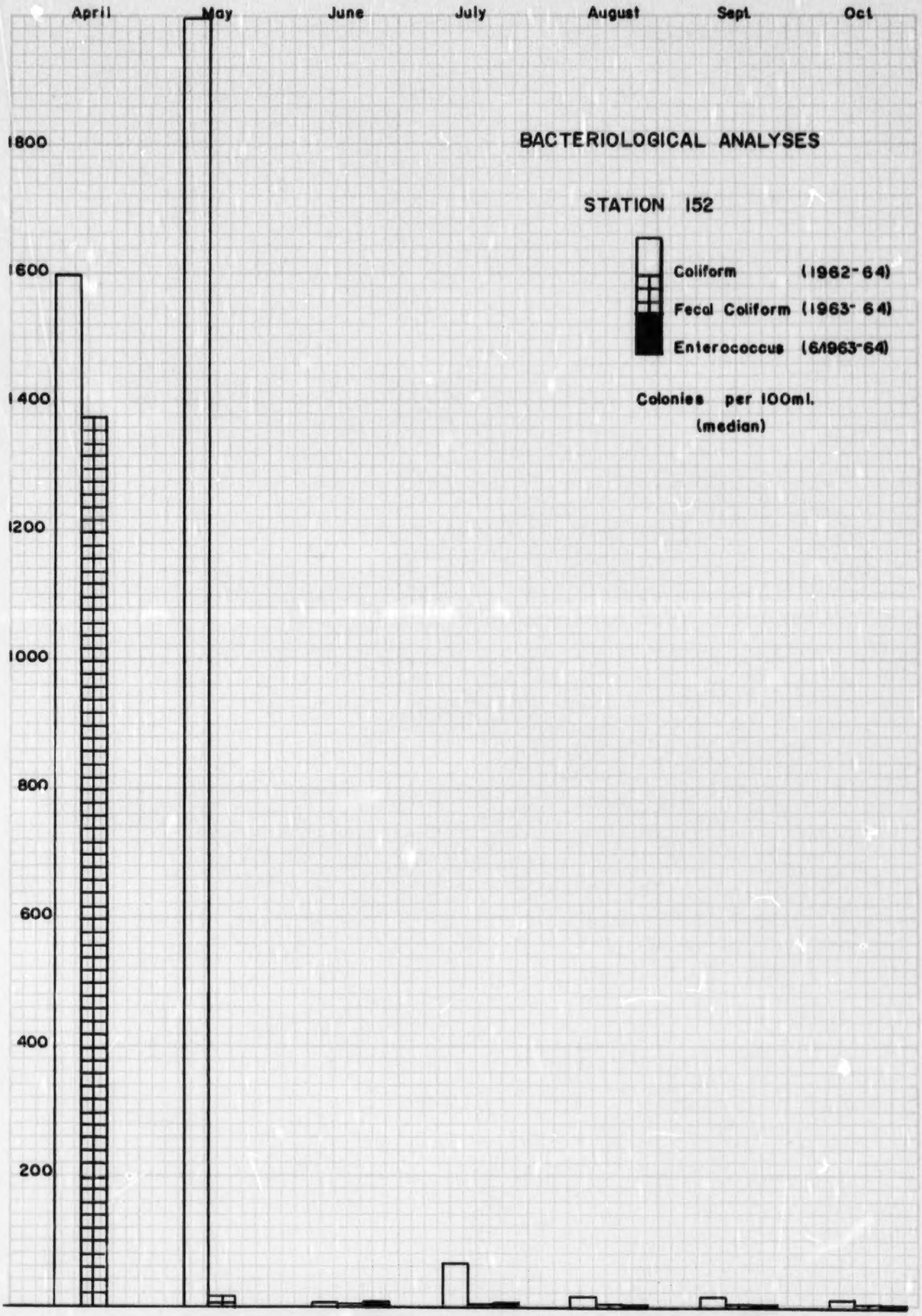

April
May
June
July
August
Sept.
Oct
1800
1600
1400
1200
1000
800
600
400
200
BACTERIOLOGICAL ANALYSES
STATION 152
Coliform (1962-64)
Fecal Coliform (1963-64)
Enterococcus (6/1963-64)
Colonies per 100ml.
(median)

Figure 28

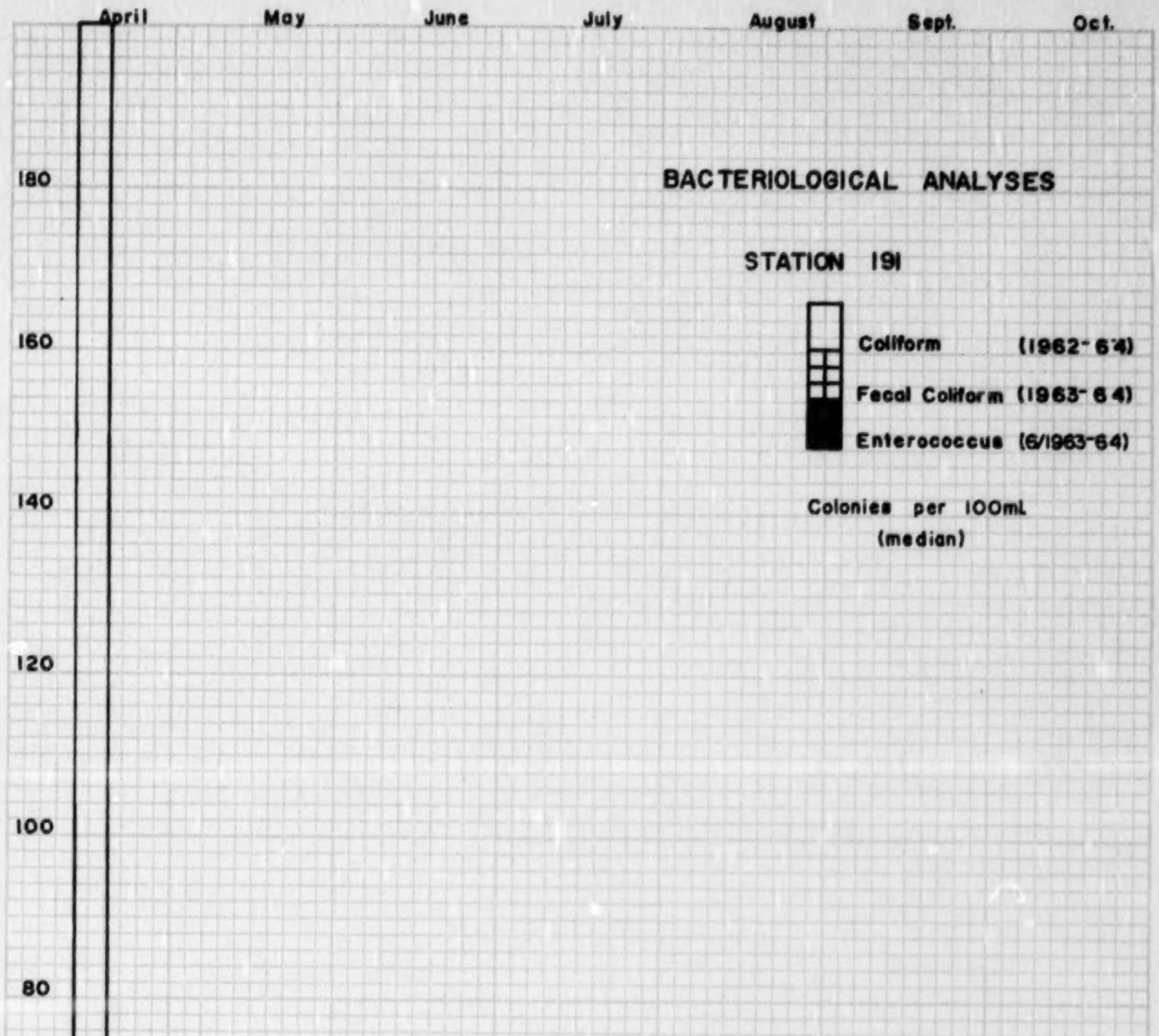

BACTERIOLOGICAL ANALYSES
STATION 191
Coliform (1962-64)
Fecal Coliform (1963-64)
Enterococcus (6/1963-64)
Colonies per 100ml
(median)
April
May
June
July
August
Sept.
Oct.
180
160
140
120
100
80
60
40
20

Figure 29

Special Studies on Fall Creek:

The quality of Fall Creek above the reservoir was studied in two stages. The first was a study of total coliform bacteria conducted in August 1962 to determine if sampling at the point selected at station 111 was representative of the entire cross section and to learn more about the quality upstream from station 111.

It was found that the waste discharges from the communities, the Indiana Reformatory, plus the soil runoff that discharged to Fall Creek above the confluence with Flat Fork Creek, had the greatest influence on coliform counts. It was also found that the sampling point at station 111 was representative of stream conditions.

The second stage of the survey of Fall Creek consisted of a diurnal study of the temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, alkalinity and hardness concentrations above the reservoir Figs. 41, 42. The BOD varied from 1.4 to 6.0 ppm. The dissolved oxygen varied from a low of 38 to a high of 131 per cent saturation. The super saturated condition occurred during the day and was caused by aquatic plants. The low dissolved oxygen concentrations occurred during the early morning before sunrise.

During the winter months of 1963-1964 a new gravel pit on the southeast shore near station 151 filled with ground water. Pumping operations to dewater the pit began in February 1964. Flow from the pit to the reservoir varied from 500 to 3,000 gpm. Analyses of the water discharged showed characteristics similar to that of the reservoir or to the ground water depending upon the water levels in the pit. A more complete study is planned in 1965, because of the conflicting interpretations of the origin of the water.

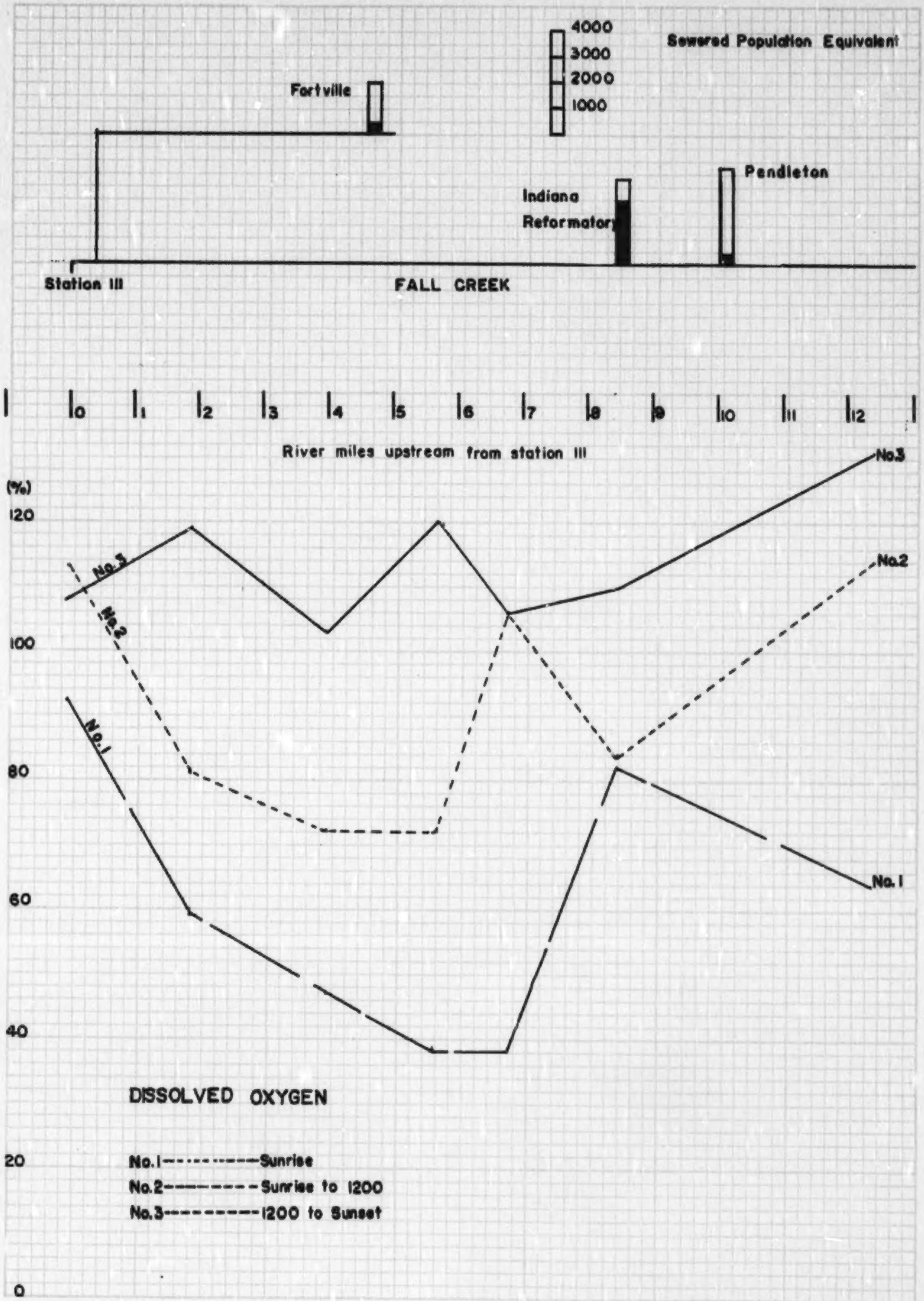

4000
3000
2000
1000
Sewered Population Equivalent
Fortville
Indiana Reformatory
Pendleton
Station III
FALL CREEK
0
1
2
3
4
5
6
7
8
9
10
11
12
River miles upstream from station III
(%)
120
100
80
60
40
20
0
No.3
No.2
No.1
DISSOLVED OXYGEN
No.1-----------Sunrise
No.2---------Sunrise to 1200
No.3---------1200 to Sunset

Figure 30

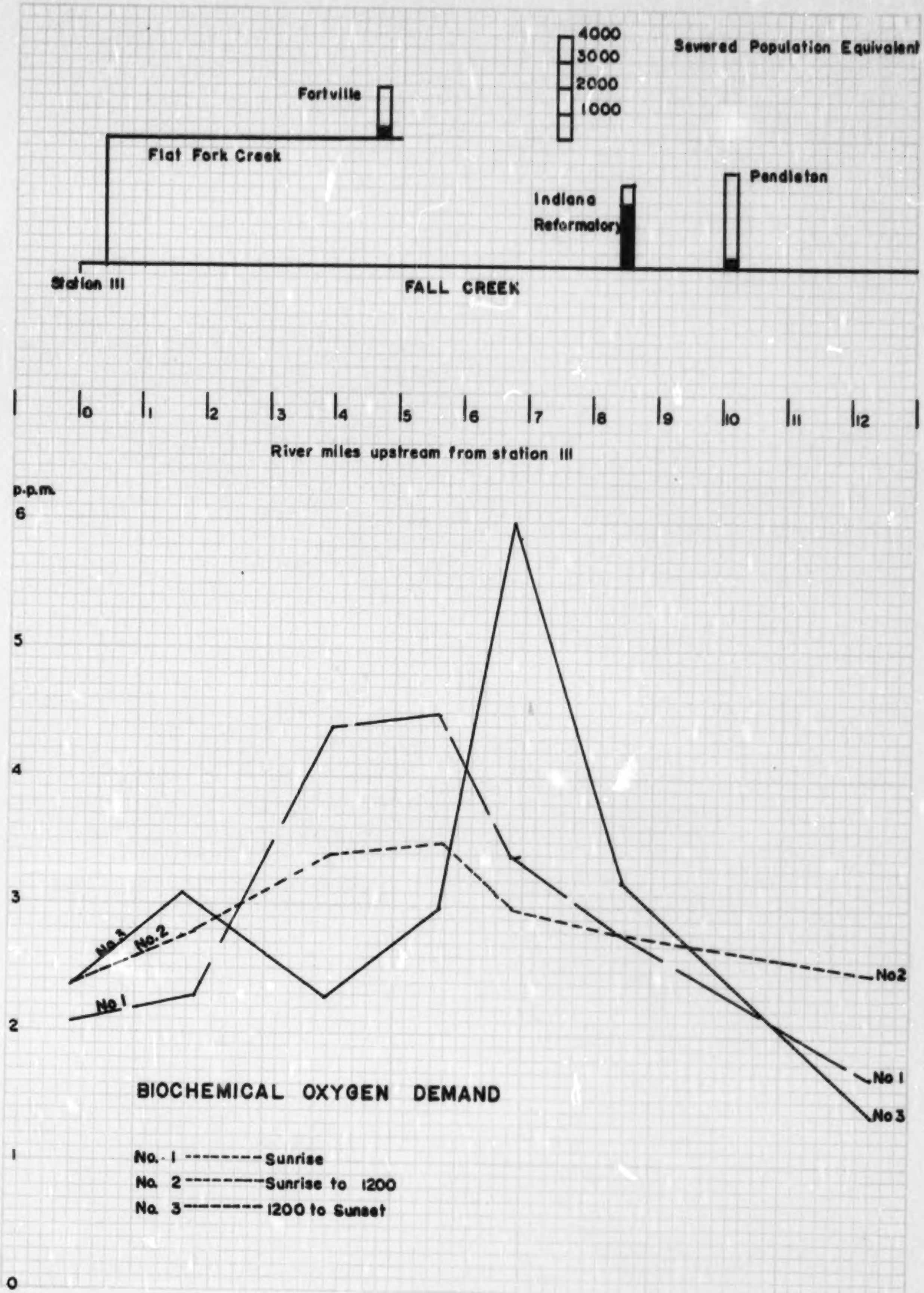

4000
3000
2000
1000
Sewered Population Equivalent
Fortville
Flat Fork Creek
Indiana Reformatory
Pendleton
Station III
FALL CREEK
0
1
2
3
4
5
6
7
8
9
10
11
12
River miles upstream from station III
p.p.m.
6
5
4
3
2
1
0
No 3
No. 2
No 1
No2
No 1
No3
BIOCHEMICAL OXYGEN DEMAND
No. 1 --------Sunrise
No. 2 --------Sunrise to 1200
No. 3 --------1200 to Sunset

Figure 31

APPENDIX A

MATHEMATICAL MODEL

MATHEMATICAL MODEL

It became apparent at any early date in the Geist Reservoir study that some type of aid was needed to assist in the interpretation of the analytical results. Hasler (1964) (12b) states "In order to decipher cause and effect better in ecology and physiology, we need to develop new ways of dealing with the interactions of multiple factors. Often it requires special and broad preparation and also collaboration with others whose mathematical talents can serve in the solution of a problem."

An evaluation of the analytical project data and the available literature was first conducted. An attempt was then made to correlate algae and inorganic nitrogen, and conferences were held with SEC personnel pertaining to correlations and trend analyses. Based on these conferences, the development of a mathematical aid was initiated.

The mathematical aid is an attempt to explain, evaluate, and forecast changes in water quality. There are many methods of approaching the development of a model. The method used for Geist Reservoir was based on photosynthesis.

The accepted general equation for photosynthesis may be expressed as:

$$\text{Solar Energy} + \text{Nutrients} + \text{Aquatic Plants} = \text{Photosynthesis} \qquad (1)$$

In the development of this aid, solar energy is equal to a physical factor times algal mass, nutrients are equal to a chemical factor times algal mass, and aquatic plants are equal to a biological factor times algal mass. Photosynthesis can be expressed as dissolved oxygen. By substitution, equation (1) becomes:

(Physical factor x algal mass) + (Chemical factor x algal mass) = (Biological factor x algal mass) = Dissolved Oxygen

or (Physical factor + Chemical Factor + Biological factor) algal mass = Dissolved Oxygen (2)

An explanation of the different variables is found in the main body of this report.

In the following mathematical development, the method of selected points was used to determine the constants. The general equation was first determined, then random sets of points were substituted for the variables. By this process, it was possible to use simultaneous equations to determine the constants. The selected points were obtained from the 1963 sampling data and 1963 records of the U. S. Weather Bureau, Weir Cook Meteorological Station, Indianapolis, Indiana.

Physical Factor:

Wind, turbidity, langleys and lux are the variables in P, the physical factor. P may be expressed as:

$$P = k_1 - a_1(z) - b_1(\log y) + c_1(x) + d_1(\log w)(p) \qquad (3)$$

Where:

z = wind velocity

y = turbidity

x = langleys

w = lux

p = correction for lux

k_1, a_1, b_1, c_1, d_1 = constants

After the constants were determined, equation (3) becomes:

$$P = -4.85 - 0.075(z) - .600(\log y) + \frac{0.25}{150}(x) + 3.77(\log w)(p) \qquad (4)$$

Chemical Factor:

Total inorganic nitrogen, soluble inorganic phosphate and bicarbonate alkalinity are the variables found in C, the chemical factor. C may be expressed as:

$$C = k_2 + a_2(N{:}P) + b_2(W) + c_2(\log Bi) + d_2(\log \frac{Bi}{N{:}P}) \qquad (5)$$

Where:

N = total inorganic nitrogen

P = soluble inorganic phosphate

$$(N{:}P) = \frac{\text{total inorganic nitrogen}}{\text{soluble inorganic phosphate}}$$

Bi = bicarbonate alkalinity

k_2, a_2, b_2, c_2, d_2 = constants

After the constants were determined, equations (5) becomes:

$$C = 4.91 + 0.067(N{:}P) + 1.675(N) + 0.551(\log Bi) - 1.106(\log \frac{Bi}{N{:}P}) \qquad (6)$$

Biological Factor:

B, the biological factor may be expressed as:

$$B = a_3\,(B_1) \qquad (7)$$

Where:

B_1 = doubling rate

a_3 = constant

As previously defined, the doubling rate is the rate of growth of the algae. Further discussion of the doubling rate follows this section.

After the constant was determined equations (7) becomes:

$$B = 0.5 (B_1) \qquad (8)$$

The biological factor is a series of algal growth rates that could occur for given ecological conditions. Maddux and Jones (1964) (9) state "A continous culture apparatus was used to measure growth rates of Nitzschia closterium and Tetraselmis sp at different temperatures and light intensities and at two different levels of nitrate and phosphate enrichment of artificial seawater. A set of symmetrical relationships was found between light, temperature and nutrient concentration in which the interaction of any two of the factors was modified by varying the third." Based upon Maddux and Jones' data, projected curves were developed for different temperatures and different amounts of nitrogen. Two nomographs, one for diatoms and the second for other phytoplankton organisms, were developed from the projected curves, see Figures (32) and (33).

A curve was developed showing a trend of the doubling rate (growth rate) time algal mass (ppm) plotted against per cent saturation of dissolved oxygen. The trend using the doubling rate is similar to the curve of the mathematical aid.

Criticism of using salt water algae and data from only two species of algae can be excepted. The reader must realize the limitations due to laboratory facilities and the number of personnel. The tools, research and knowledge of aquatic life, available leaves much to be desired. This project is an investigative project and pure and objective research were beyond the capabilities of the project.

At this time a more complete explanation of the constants is needed. As stated above, the constants were determined by the method of selected points. They were also weighted, based on their estimated effect on photosynthesis.

General Factor:

Physical factor, chemical factor and biological factor are variables found in F, the general factor. F may be expressed as:

$$F = K + aP + bC + cB \qquad (9)$$

These constants were also determined by the method of selected points from the 1963 data, and were weighted, based on their estimated effect on photosynthesis. After the constants were evaluated, equation (9) becomes:

$$F = -0.05 + 0.016P + 0.034C + B \qquad (10)$$

Substituting for P, C and B from equation (4), (6) and (7), equation (10) becomes:

$$F = 0.039 - 0.0004(z) - 0.010(\log y) + \frac{0.04}{150}(x) + 0.060(\log w)(p) + 0.002(N:P) + 0.057(N) + 6.019(\log Bi) - 0.038\left(\log \frac{Bi}{N:P}\right) + 0.5B_1 \qquad (11)$$

As stated above, (P + C + B) (algal mass) = Dissolved Oxygen. This equation may be expressed as:

$$F \times M = D\,O \qquad (12)$$

Where:

$$F = (P + C + B)$$

M = algal mass

D O = per cent saturation dissolved oxygen.

The plotting of equation (12) is shown in Figure (35). Algal mass and dissolved oxygen were determined by sampling. F, the general factor, was determined by equation (11). The data obtained in 1964 was used to check equation (12). All samples were taken before noon of each sampling day. Monthly means were then determined and used in the equation.

From the plotting of equation (12), the best fitting curve, $x = ay^2 + by + c$, was developed. Using the method least squares, this equation becomes:

$$x = 0.0116y^2 - 1.91y + 83.65 \tag{13}$$

Where:

$x = F \times M$

$y = D\,O$

The equation, $F \times M = D\,O$, satisfies two of the three objectives. The project staff believes that the equation explains and evaulates changes in water quality, but it can not be used for forecasting. A second equation must be developed for this purpose. Before this equation can be developed, additional concentrated studies in the areas of diurnals, N:P ratios and solar radiation are needed.

This second equation may be in the form:

$$F \times M = N:P \tag{14}$$

A curve has been developed relating N:P to D. O., Figure (34). This curve was developed based on the 1963 and 1964 data. There appear to be two major limitations:

1. All sampling was done before noon of each sampling day.
2. N:P is expressed as a ratio.

Project plans at this time are to conduct an extensive diurnal sampling program in order to evaluate equation (14) for each 24 hour period. After this evaluation, the curve shown in Figure (34) could be projected.

The second limitation does not appear to be of great significance. However, the problem is that N:P is expressed as a ratio and not as a numerical value. This means that if the ratio remains the same, but the inorganic nitrogen and the soluble inorganic phosphate increase or decrease, the indicated dissolved oxygen will not change. To solve this problem, it is planned to set up known N:P ratios, but vary the amount of nitrogen and phosphate. Samples would be collected and D. O., N:P ratios and algal mass would be determined. The amount of nitrogen and phosphate would then be changed but maintaining the same ratios. These samples would be stored in the laboratory at a controlled temperature and with a controlled amount of light. After a given length of time, D. O., N:P ratios and algal mass would again be determined. Based on the information obtained from these controlled studies, the curve shown in Figure (34) could be adjusted. After the above has been accomplished, it is believed the final equation F x M = N:P could be developed. In equation (12) F x M = D O and the curve in Figure (34) relates N:P to D. O. Substitution of N:P for D. O. equation (12) becomes: F x M = N:P.

It is also believed that a range of values for each month can be developed for F. Equation (14) would then become:

$$K \times M = N{:}P \qquad \text{or} \qquad M = \frac{N{:}P}{K} \qquad (15)$$

Where:

M = algal mass

$$N{:}P = \frac{\text{total inorganic nitrogen}}{\text{soluble inorganic phosphate}}$$

K = constant (range of values for F)

Equation (15) would make it possible to forecast algal mass based on nitrogen and phosphate.

Doubling Rate for Diatom Algae

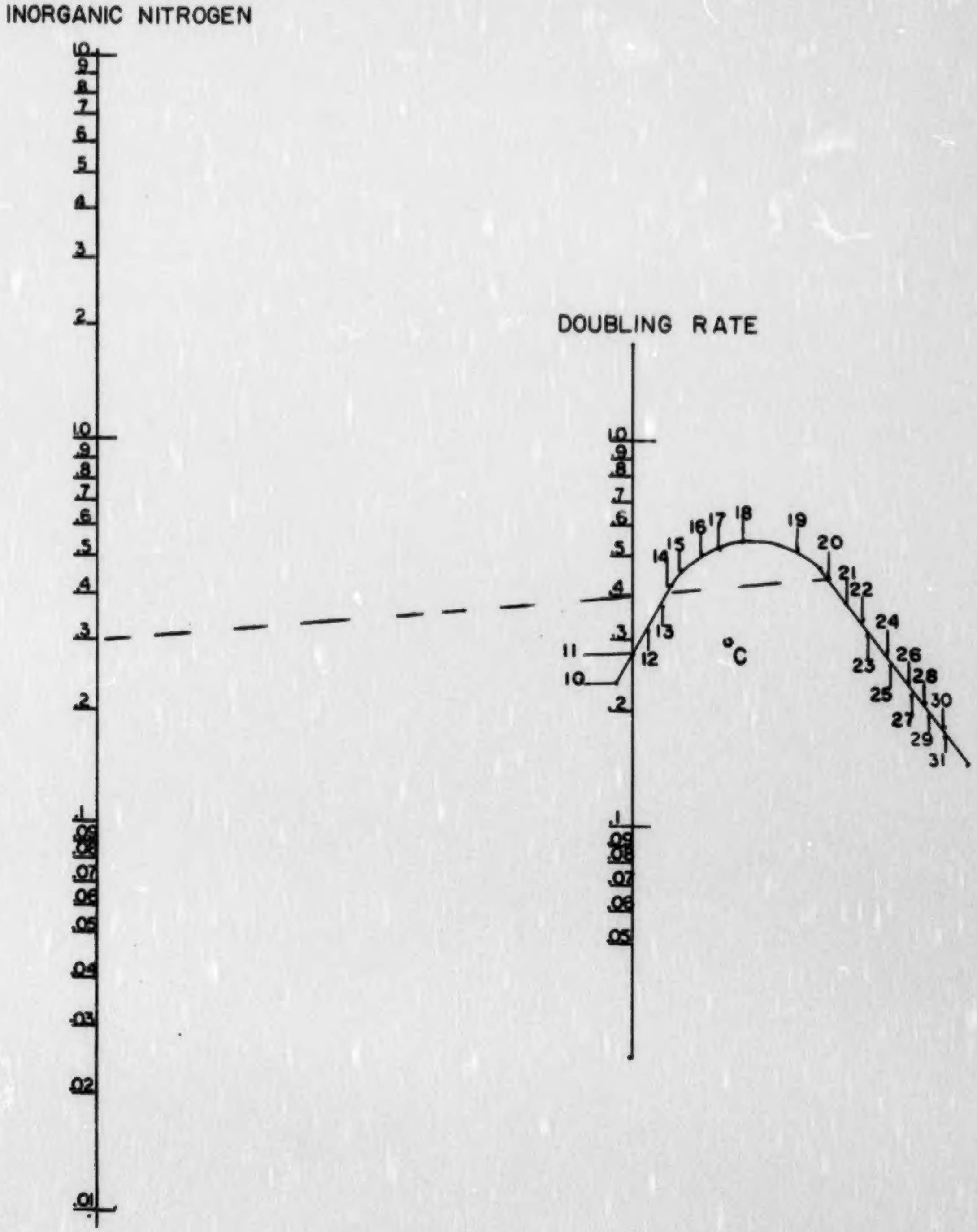


Figure 32

Doubling Rate for Green, Blue-Green, and Pigmented Flagellate Algae

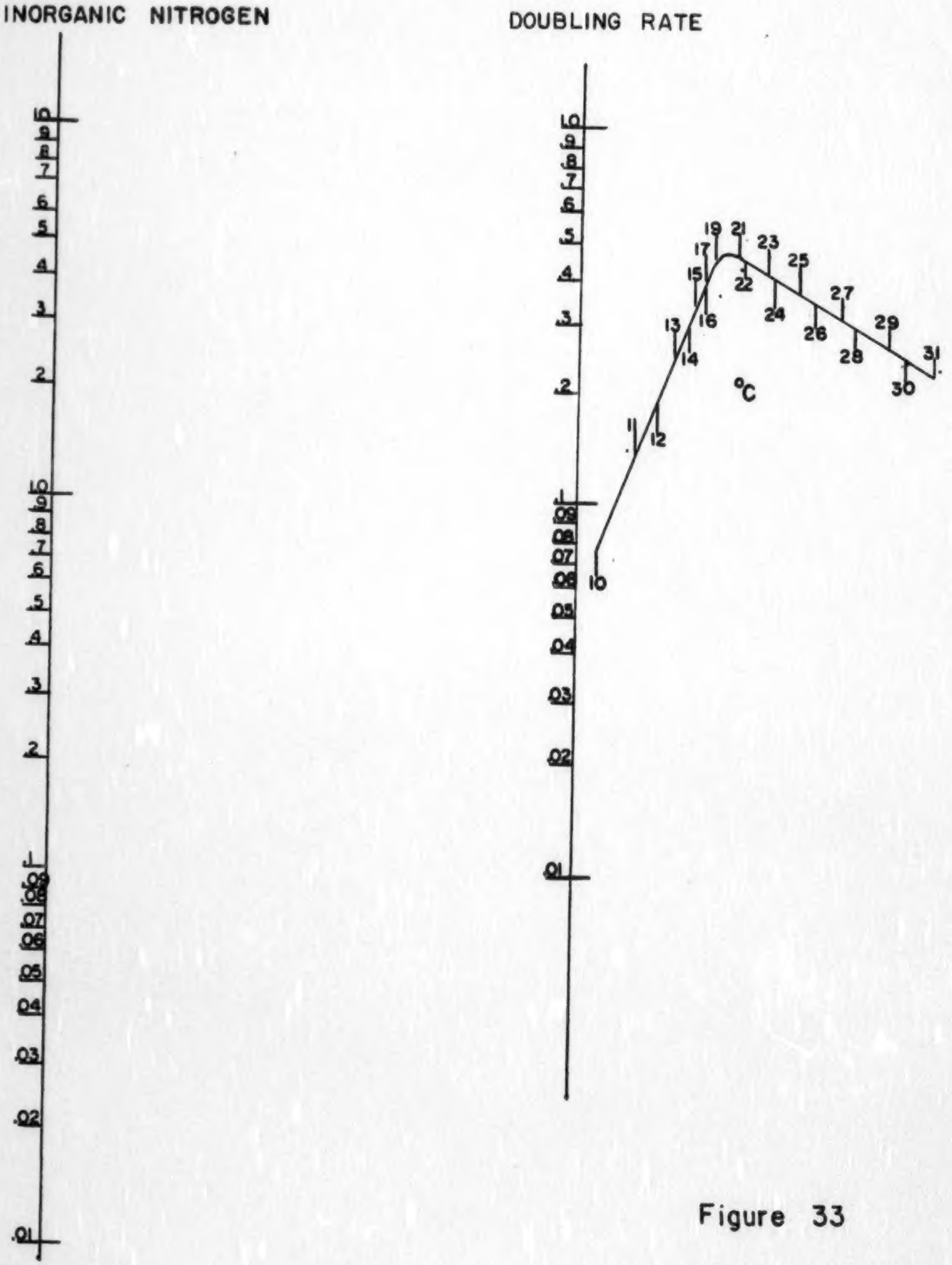


Figure 33

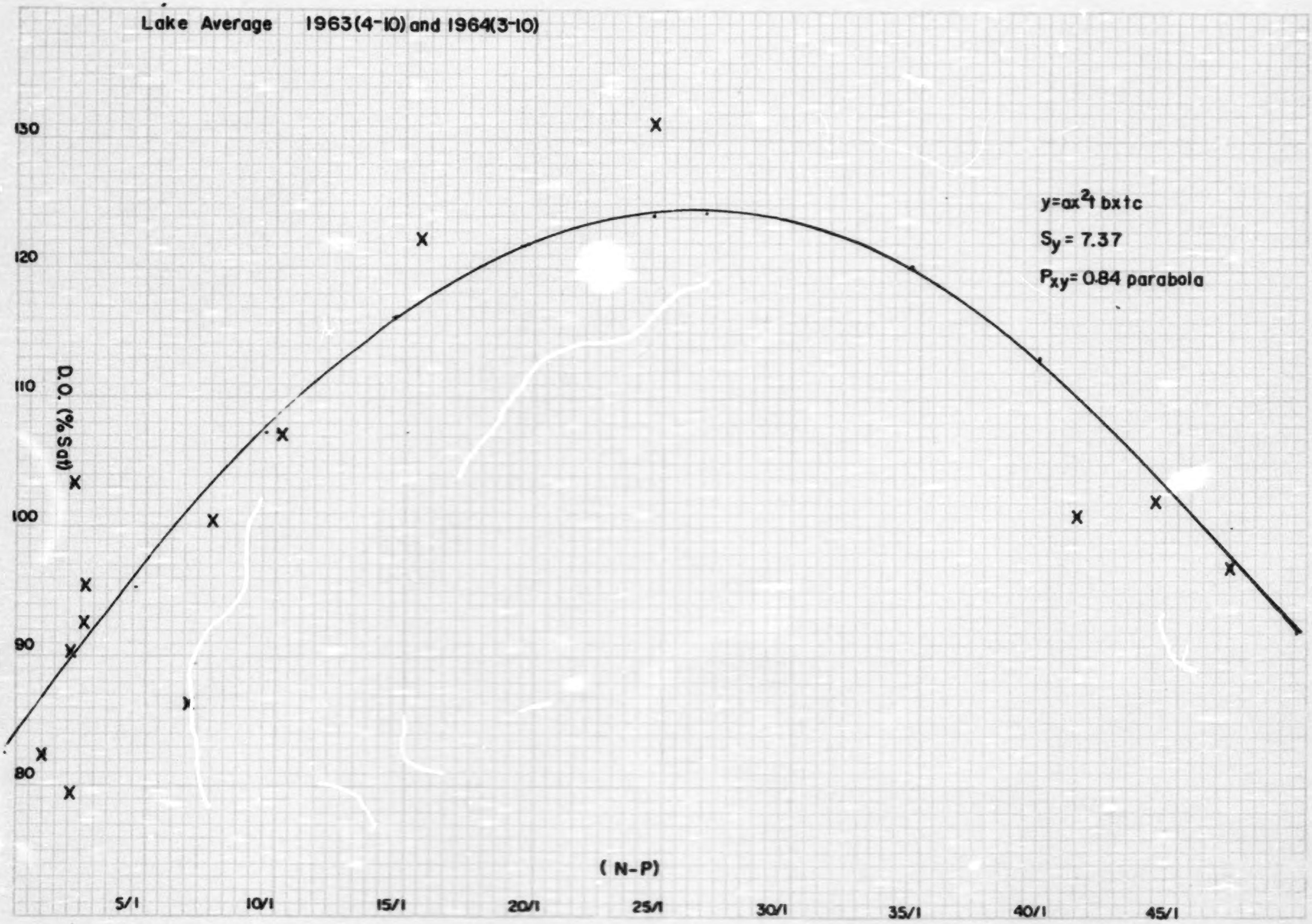
Lake Average 1963(4-10) and 1964(3-10)
$y=ax^2+bx+c$
$S_y = 7.37$
$P_{xy} = 0.84$ parabola
D.O. (% Sat)
130
120
110
100
90
80
(N-P)
5/1
10/1
15/1
20/1
25/1
30/1
35/1
40/1
45/1

Figure 34

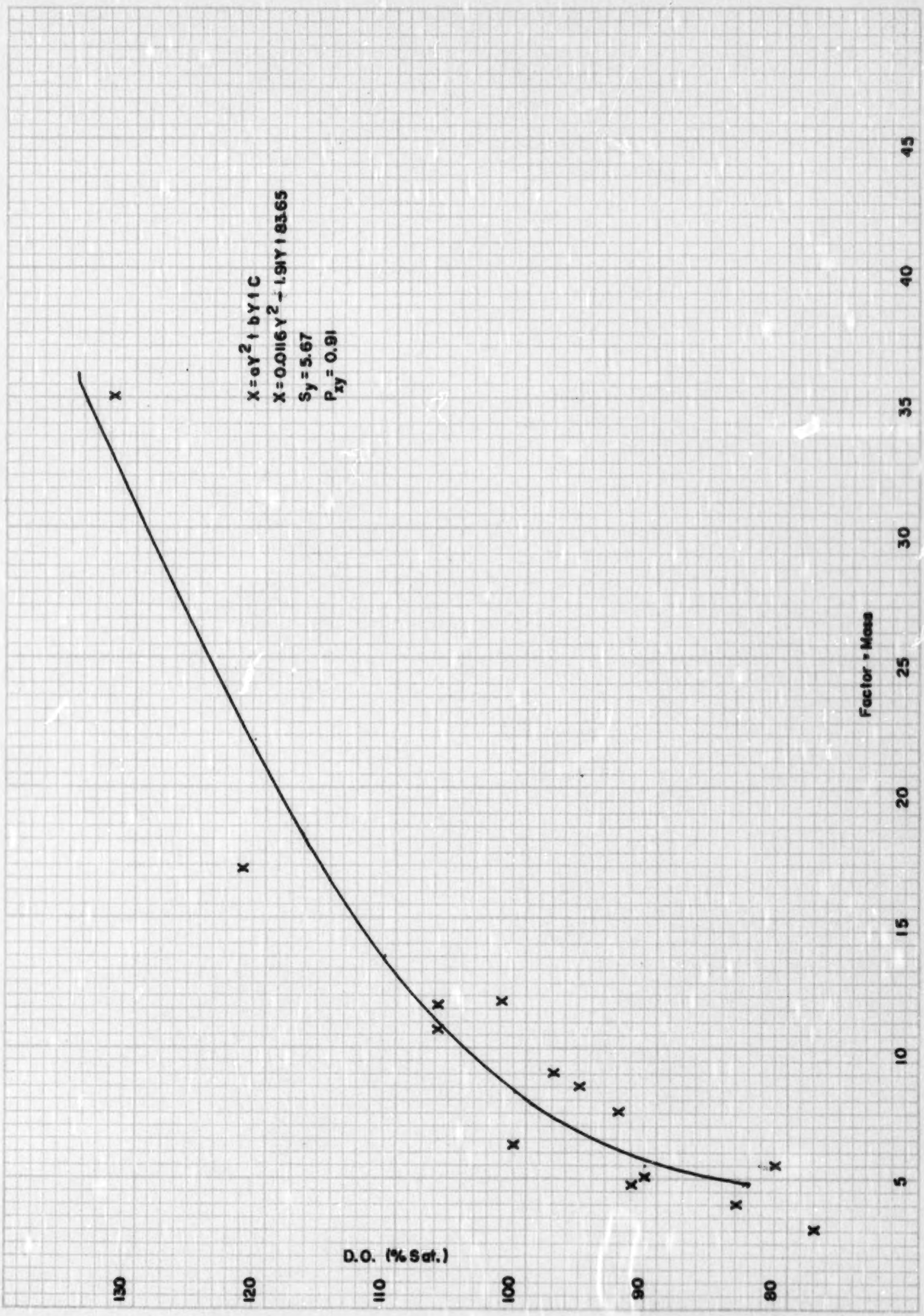

X = aY^2 + bY + C
X = 0.0116Y^2 − 1.91Y + 83.65
S_y = 5.67
P_{xy} = 0.91
D.O. (% Sat.)
130
120
110
100
90
80
Factor • Mass
5
10
15
20
25
30
35
40
45

Figure 35

APPENDIX B

CLIMATOLOGICAL INFORMATION

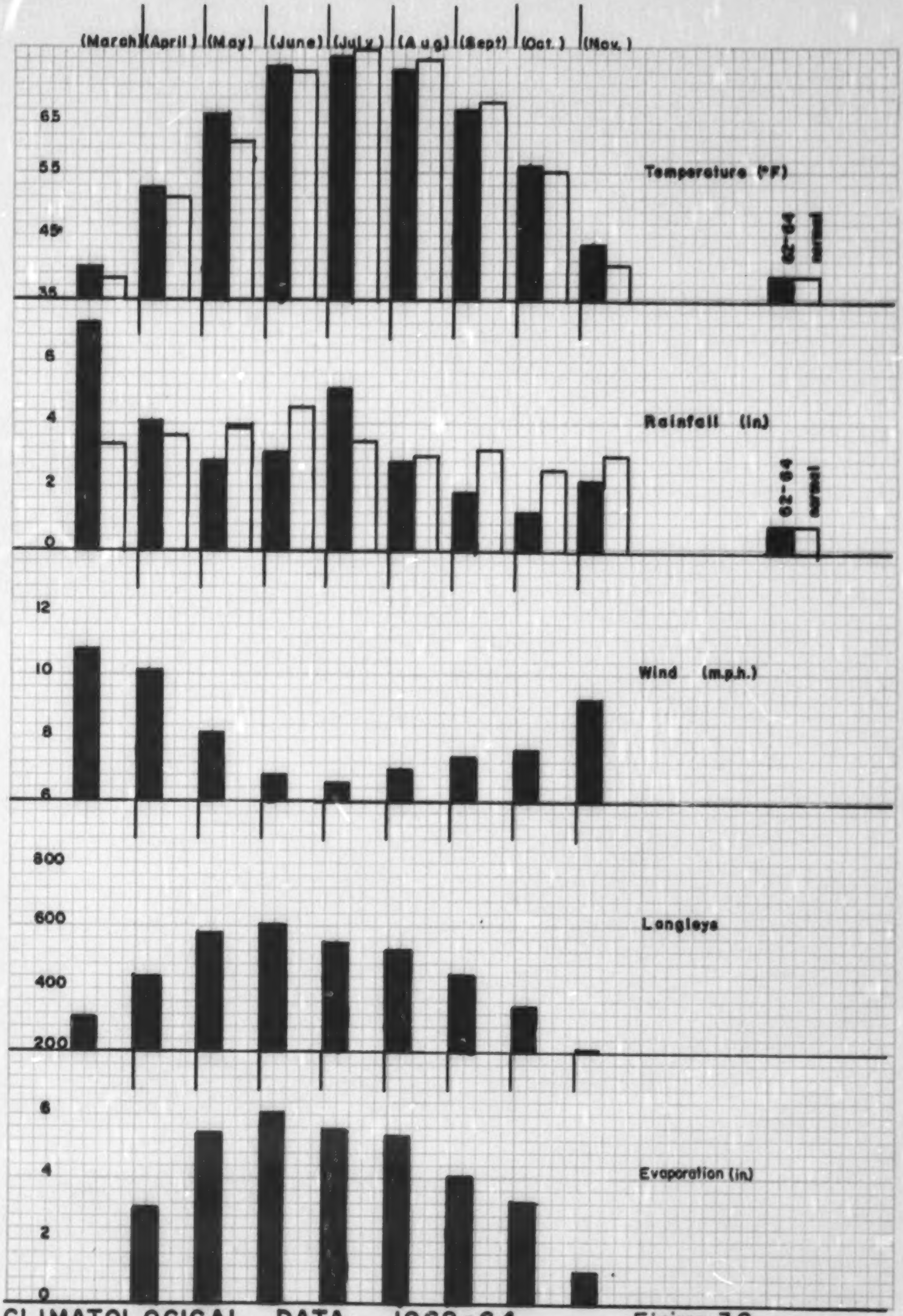
Climatological Information:

The average monthly temperatures for period 1962-1964, (Fig. 36), and for 1964 (Fig. 37) followed a similar trend from January to June. March was about 2 degrees above normal. April and May were 3 to 4 degrees above normal. The warm trend of April and May continued into June, but with a differential that was less than half as great. August and September were about 2 degrees cooler than normal during the 3 year period· while, August 1964 was about 1 degree above normal. In general the weather was slightly warmer than the normal monthly mean and then dropped to about or below the average. Temperatures above normal in April each year probably accelerated the early growth of the biological life.

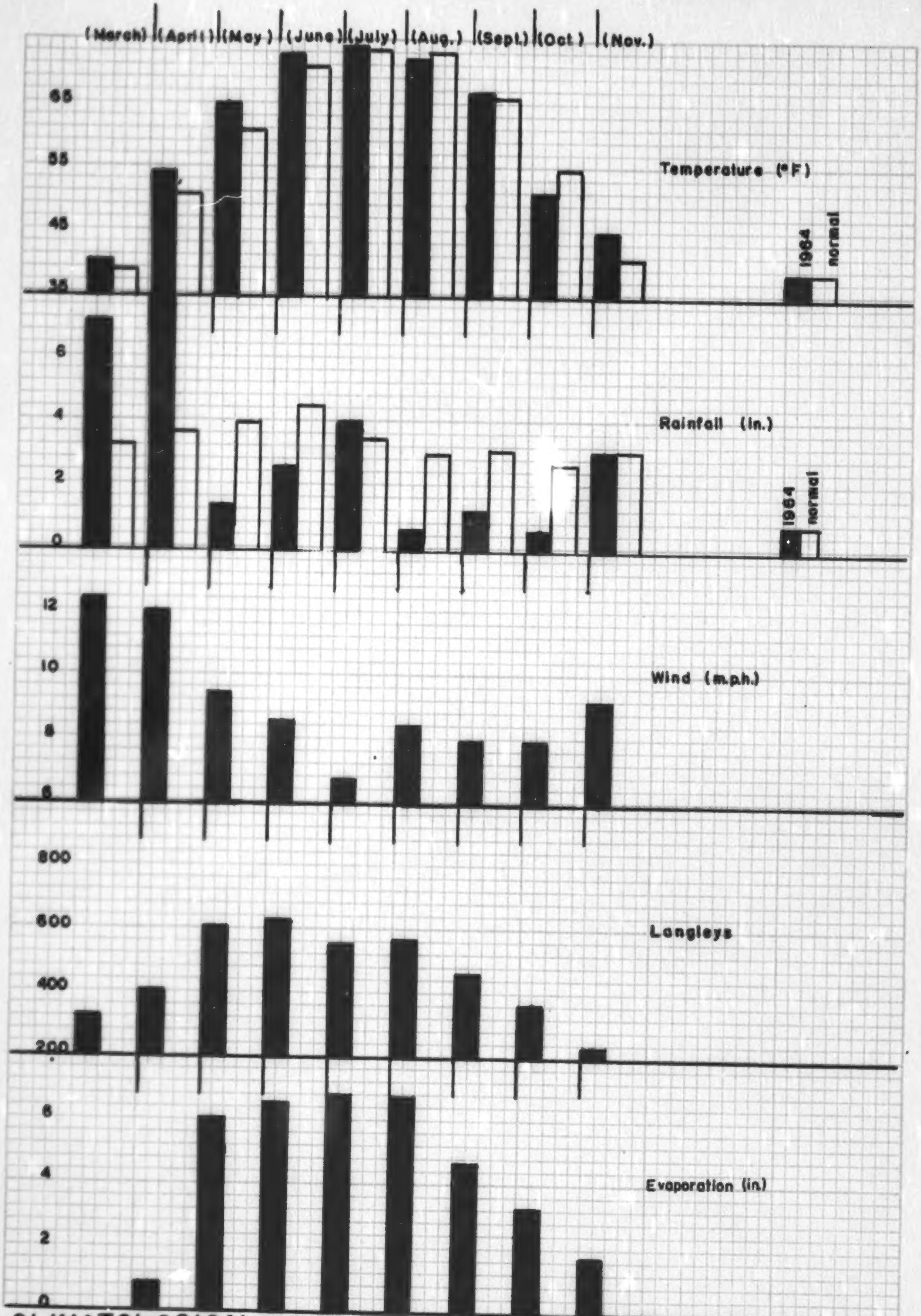
The bar graphs of rainfall, Figs. 36 and 37, are taken from the Indianapolis Weather Bureau data for a 40 year period of record and provide data concerning the amount of precipitation that fell with-in a 20 mile radius of the reservoir. The data can not be used to determine the amount that fell on the reservoir during any one storm, but provides reliable data on the amount that fell on the reservoir within the period of a month.

Figures 38 and 39 show reservoir inflow and outflow in mgd. Figure 40 shows the average monthly reservoir level for the three years of the study. The reservoir usually begins to fill in January after it has been drawn down about 3 to 4 feet in the fall months, and begins to flow over the spillway during the first week of March. The reservoir usually remains full until about the first week in August when it drops below the crest of the dam and continues to fall until it starts to fill the next year. During the first year of the study, 1962, the reservoir was full on January 1 and remained full until August 10. In 1963, the reservoir level first dropped below the crest of the dam on July 2, and continued to drop until it was down more than 6 feet by the end of December. Although the latter part of 1964 was about average, this year can not be considered average either because there was an unusually large deficit in volume of storage at the beginning of 1964, followed by extremely large inflow in April. Spring rains usually caused inflows to increase significantly in March.

Temperature, rainfall, wind speed, solar radiation and evaporation data for the months included in the sampling seasons are shown in Figs. 36 and 37. Evaporation pan data was obtained from the Indianapolis Water Company. All other data was obtained from the U. S. Weather Bureau Station at Indianapolis. The solar radiation unit, langleys, is gram calories per square centimeter.



CLIMATOLOGICAL DATA 1962-64 Figure 36



CLIMATOLOGICAL DATA 1964

Figure 37

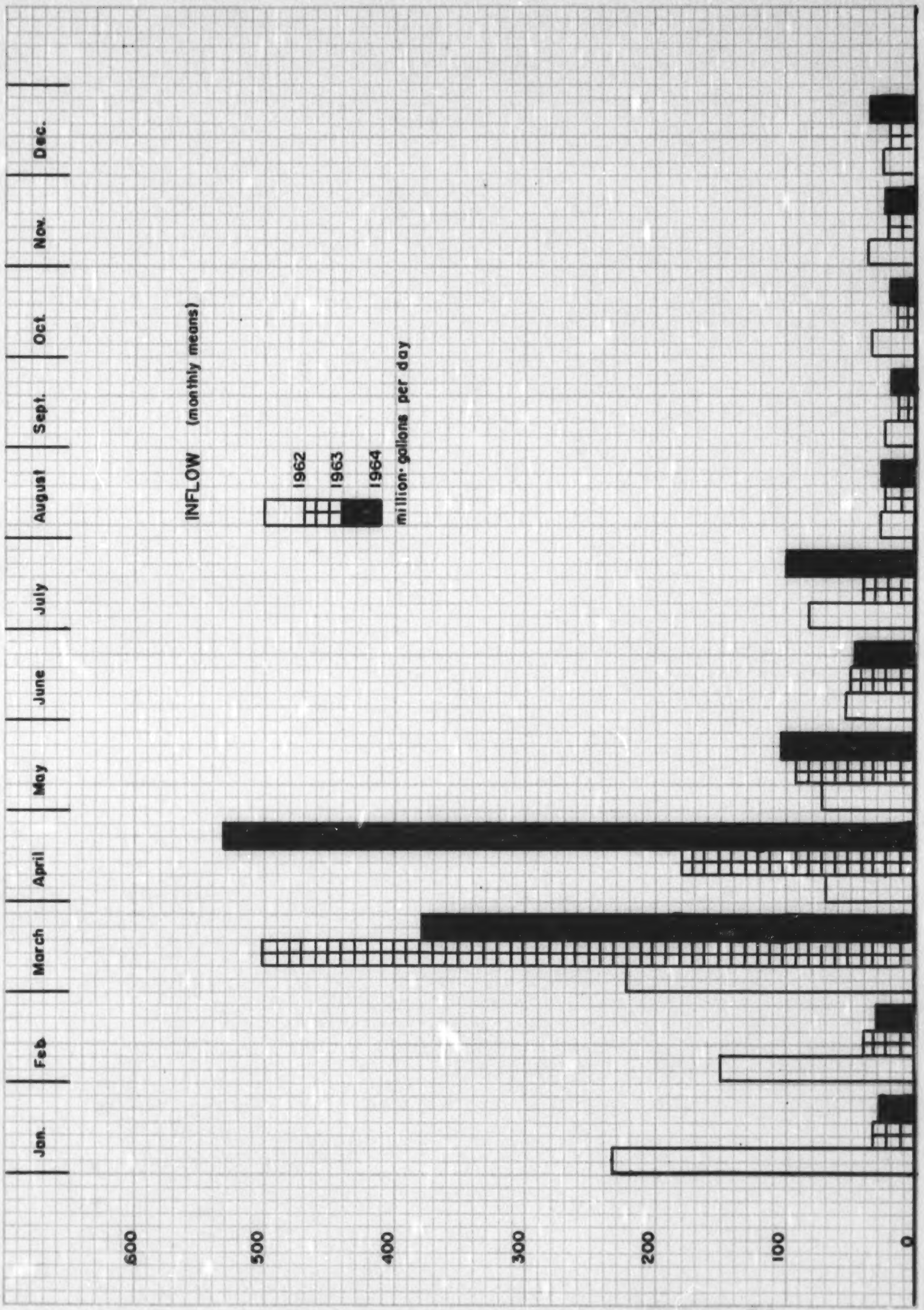

INFLOW (monthly means)
1962
1963
1964
million gallons per day
Jan.
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
600
500
400
300
200
100
0

Figure 38

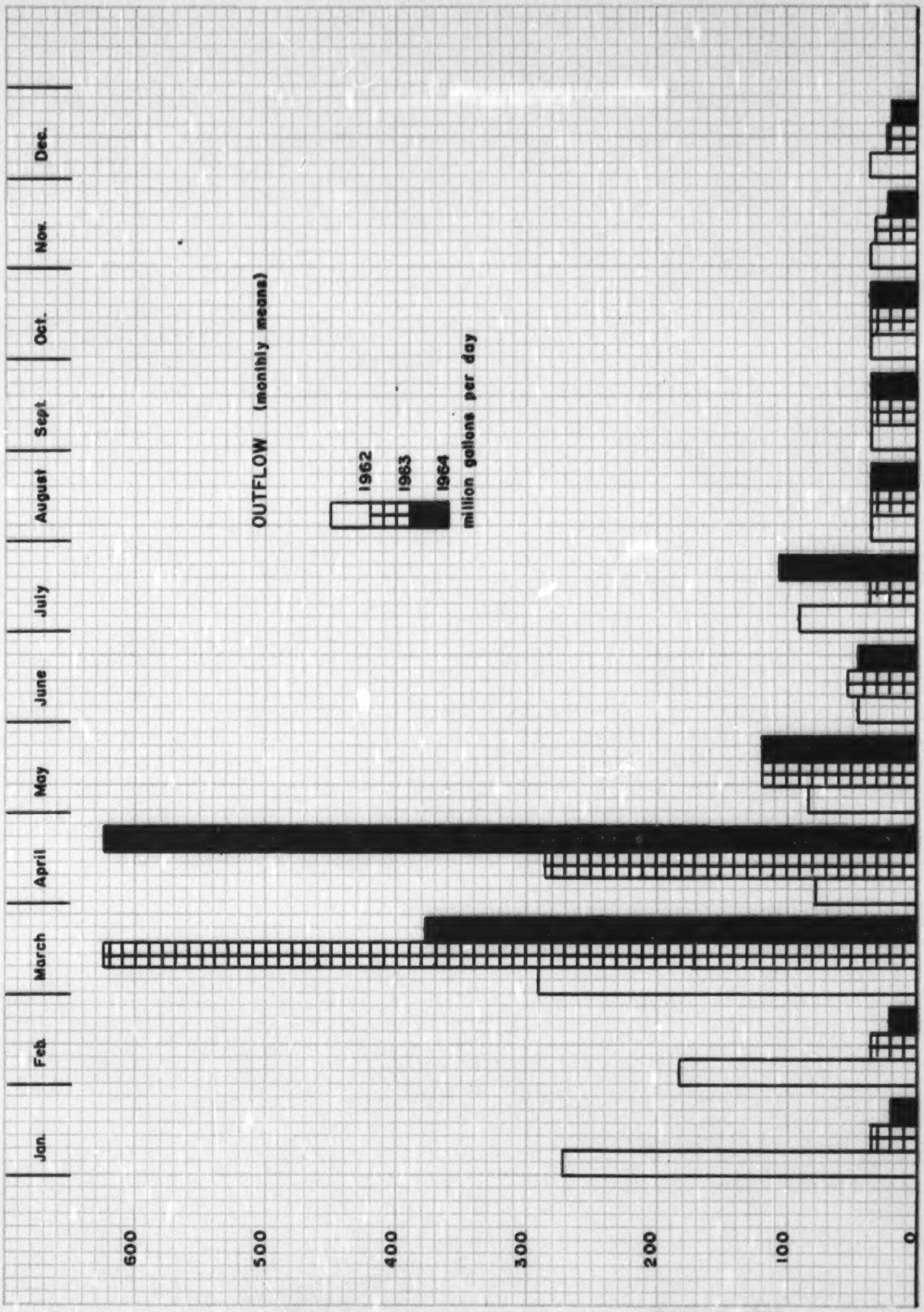

OUTFLOW (monthly means)
1962
1963
1964
million gallons per day
Jan.
Feb.
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
0
100
200
300
400
500
600

Figure 39

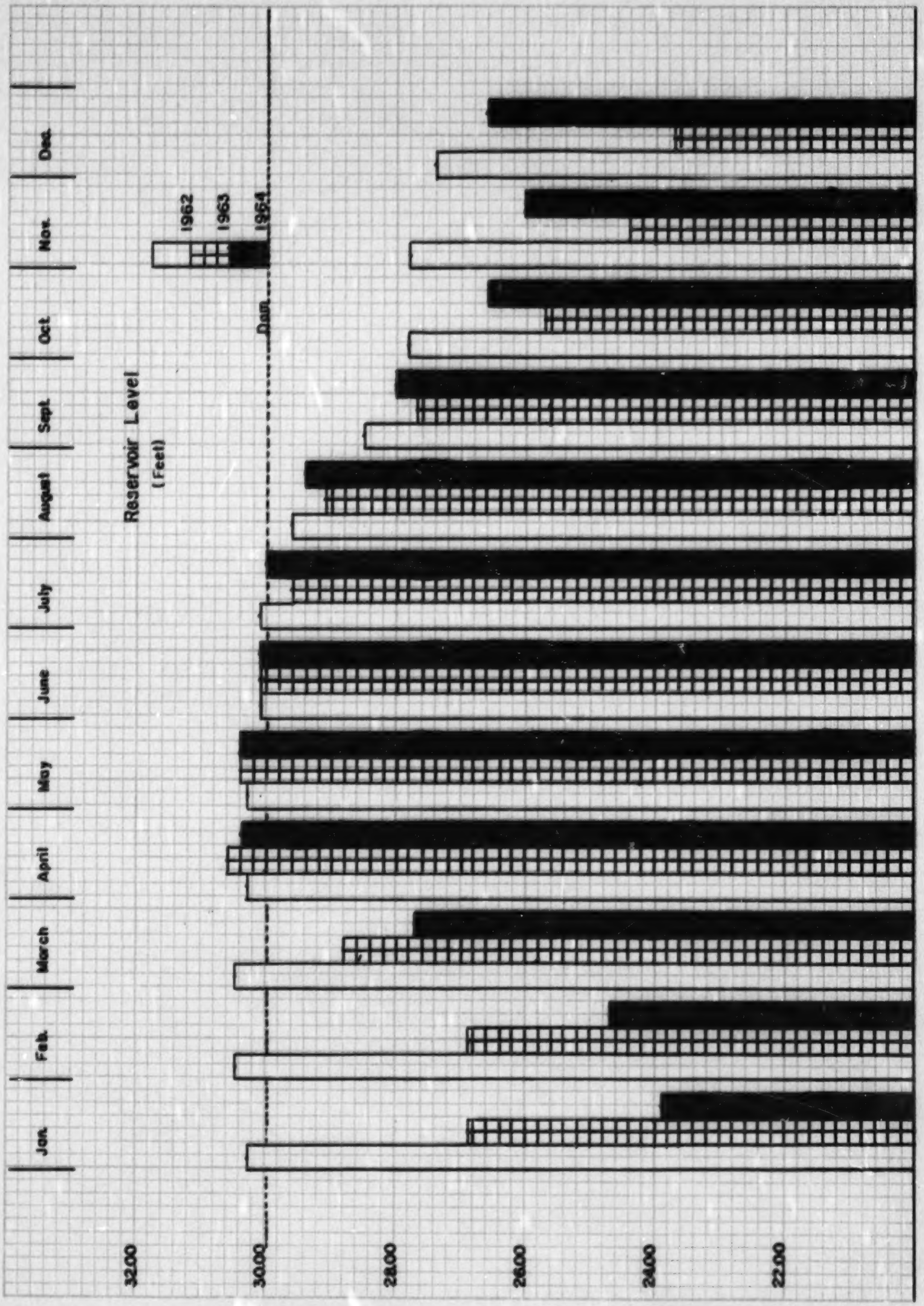
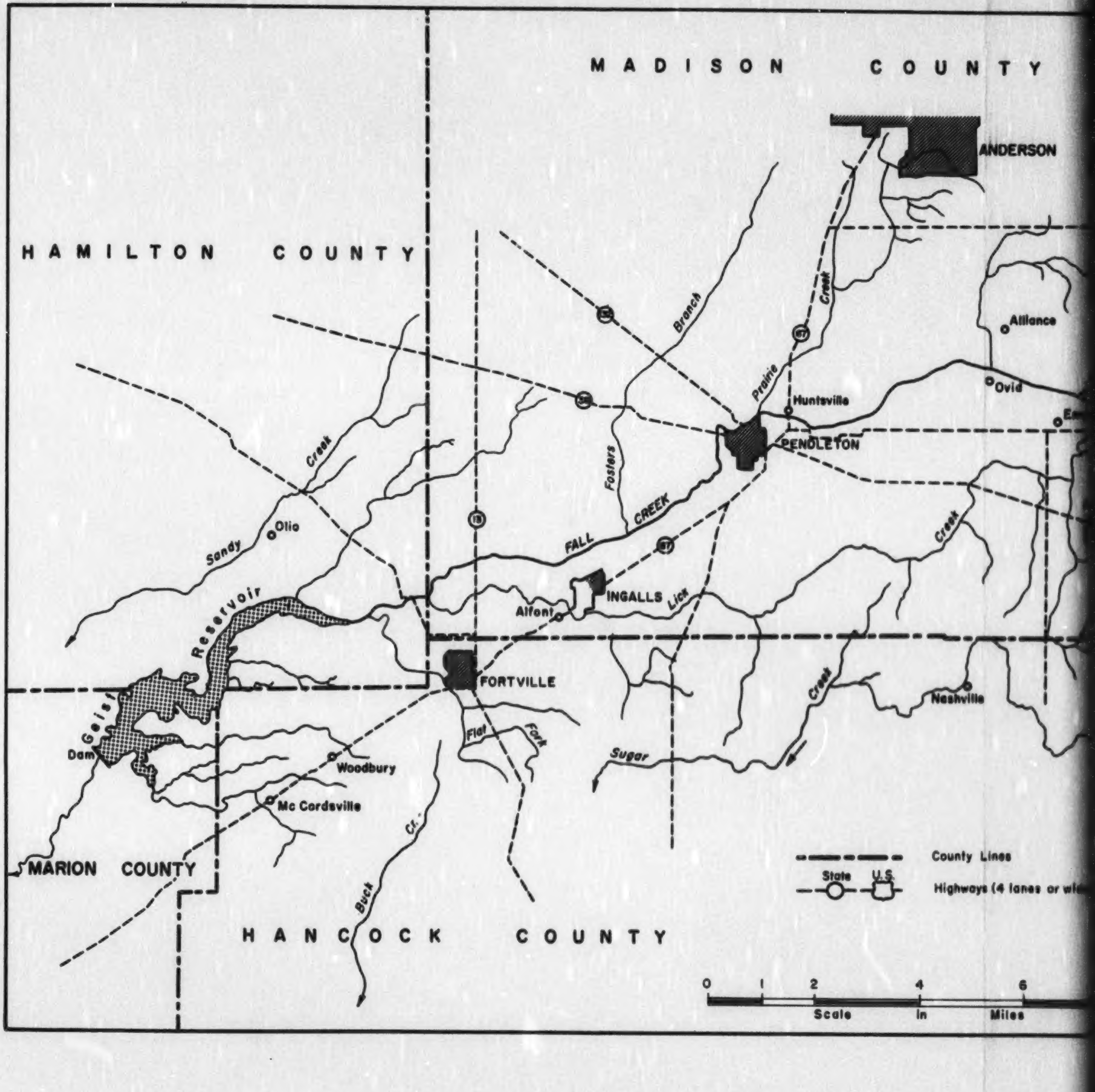

Jan.
Feb.
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Reservoir Level
(Feet)
1962
1963
1964
Dam
32.00
30.00
28.00
26.00
24.00
22.00

Figure 40


MADISON COUNTY
ANDERSON
HAMILTON COUNTY
Alliance
Ovid
Huntsville
PENDLETON
Branch
Prairie
Creek
Fosters
FALL CREEK
132
38
67
13
Sandy Creek
Olio
Reservoir
Geist
Dam
INGALLS
Alfont
Lick
Creek
FORTVILLE
Flat Fork
Sugar
Creek
Nashville
Woodbury
Mc Cordsville
Buck Cr.
MARION COUNTY
HANCOCK COUNTY
County Lines
State
U.S.
Highways (4 lanes or wi
0
1
2
4
6
Scale in Miles

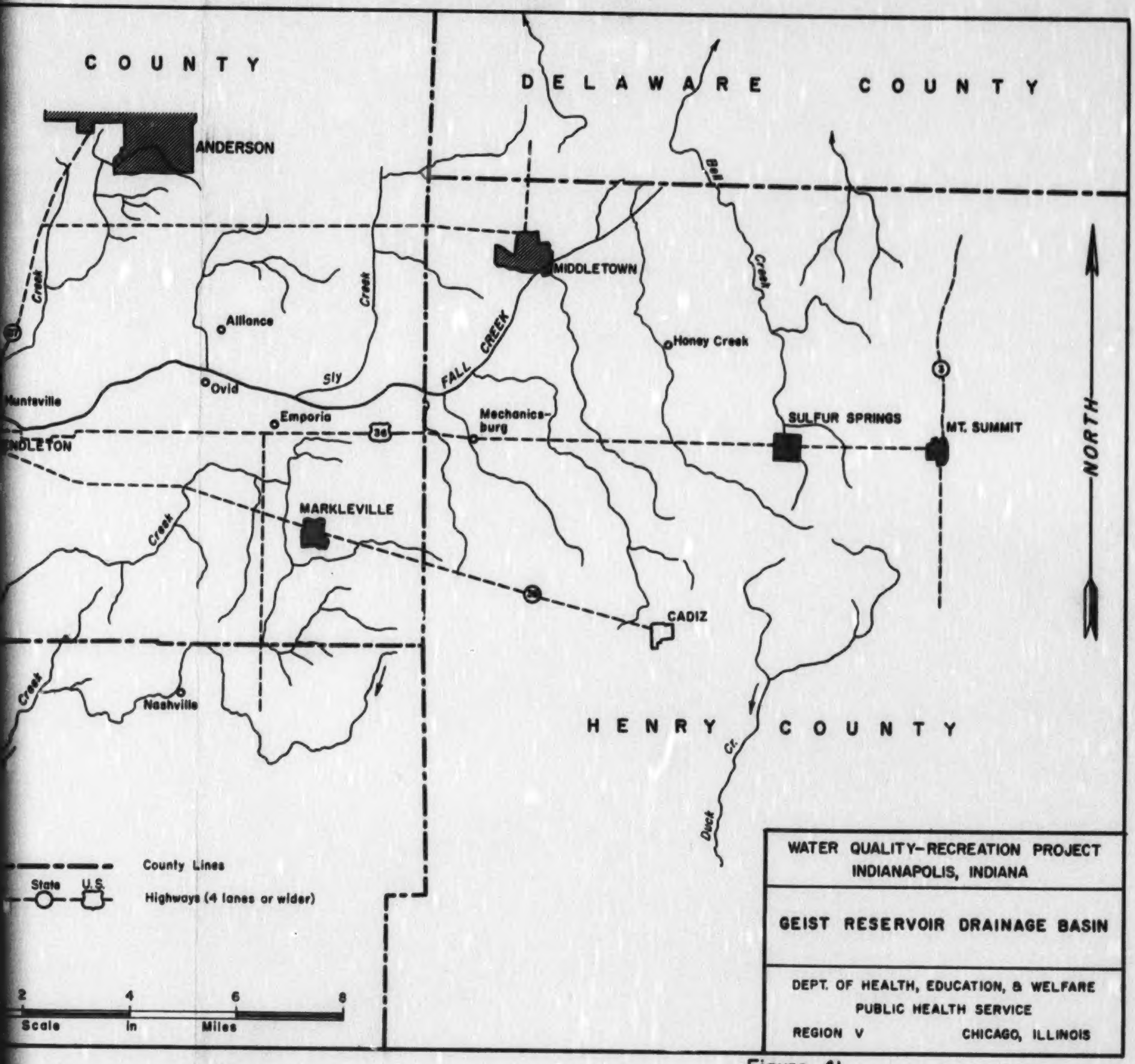
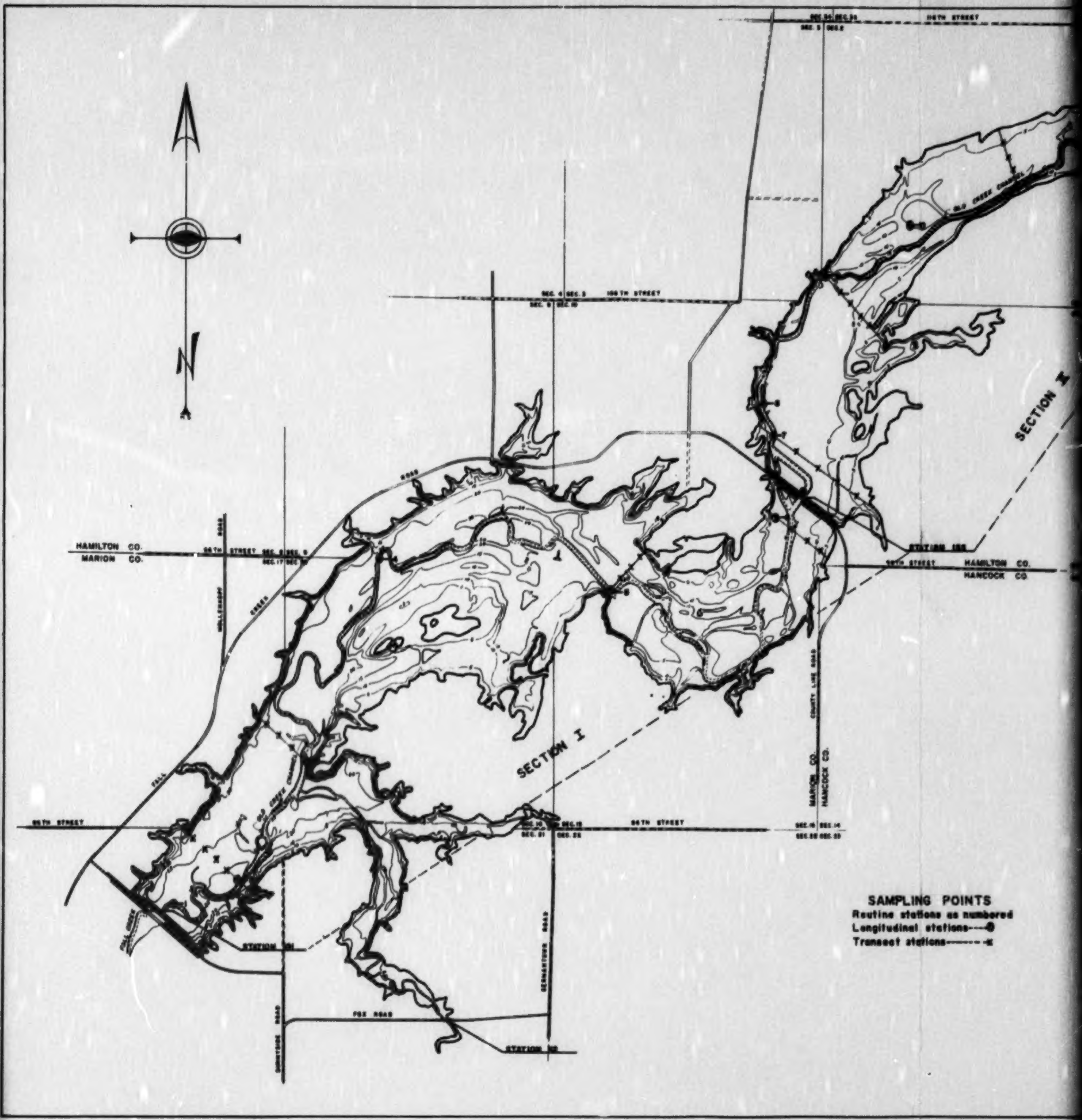
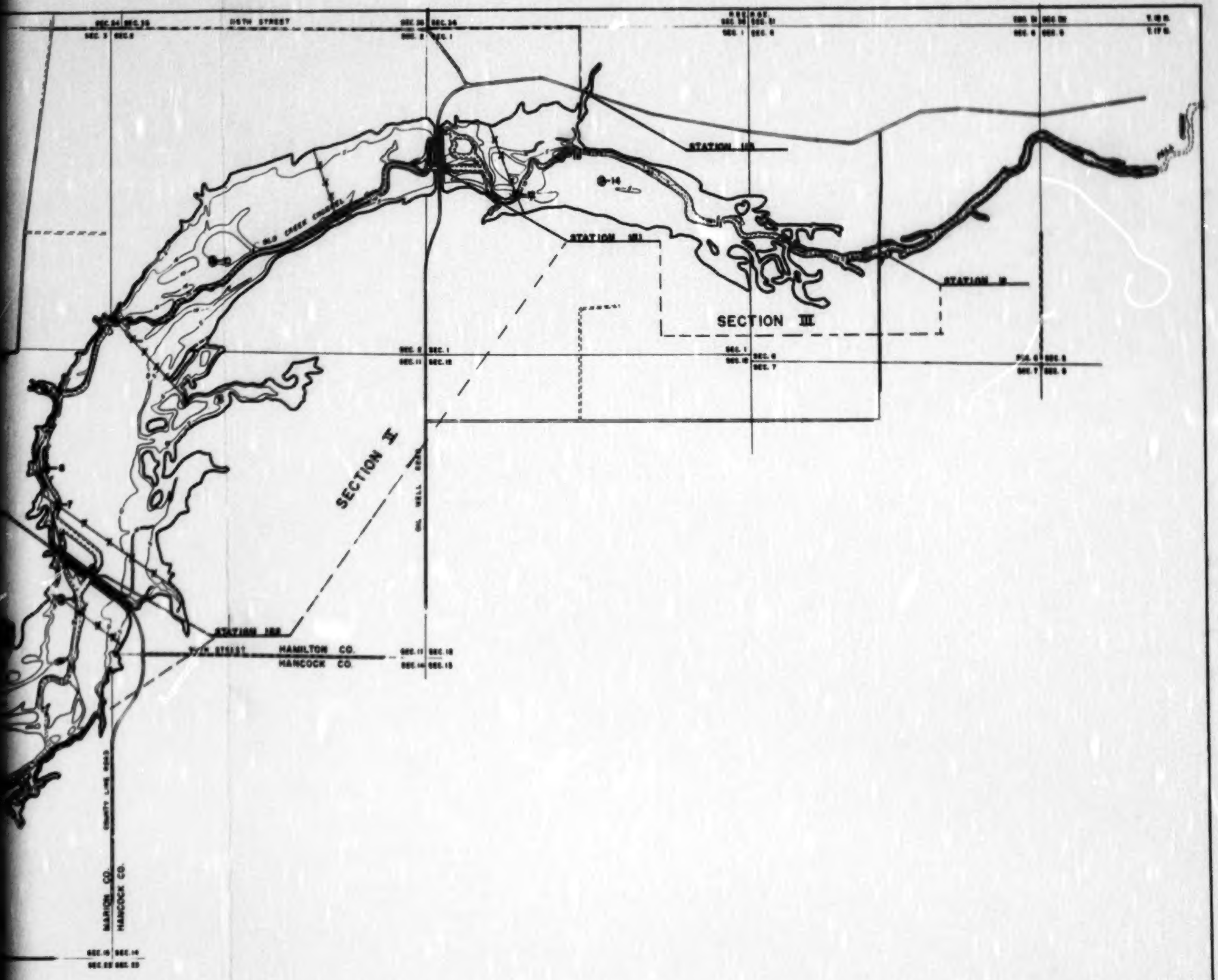

COUNTY
DELAWARE COUNTY
ANDERSON
Creek
MIDDLETOWN
Bell Creek
Alliance
Creek
Honey Creek
FALL CREEK
Sly
Ovid
Huntsville
Emporia
36
Mechanicsburg
SULFUR SPRINGS
3
MT. SUMMIT
NORTH
NDLETON
MARKLEVILLE
Creek
36
CADIZ
Creek
Nashville
HENRY COUNTY
Cr.
Duck
County Lines
State
U.S.
Highways (4 lanes or wider)
2
4
6
8
Scale in Miles
WATER QUALITY–RECREATION PROJECT
INDIANAPOLIS, INDIANA
GEIST RESERVOIR DRAINAGE BASIN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

Figure 41


116TH STREET
106TH STREET
96TH STREET
86TH STREET
HAMILTON CO.
MARION CO.
HANCOCK CO.
SECTION I
SECTION II
OLD CREEK CHANNEL
FALL CREEK
STATION 151
STATION 152
STATION
FOX ROAD
GERMANTOWN ROAD
SUNNYSIDE ROAD
COUNTY LINE ROAD
SAMPLING POINTS
Routine stations as numbered
Longitudinal stations----⊕
Transect stations--------x


SEC. 34
SEC. 35
SEC. 3
SEC. 2
96TH STREET
SEC. 36
SEC. 1
STATION 110
OLD CREEK CHANNEL
STATION 181
STATION 18
SECTION III
SEC. 1
SEC. 6
SEC. 12
SEC. 7
SEC. 2
SEC. 11
SEC. 12
SEC. 8
SECTION II
OIL WELL ROAD
STATION 182
HAMILTON CO.
HANCOCK CO.
SEC. 11
SEC. 14
SEC. 15
COUNTY LINE ROAD
MARION CO.
HANCOCK CO.
SEC. 15
SEC. 14
SEC. 22
SEC. 23
T. 18 N.
T. 17 N.

SAMPLING POINTS
Routine stations as numbered
Longitudinal stations----⊕
Transect stations-------⊣

DATA

APPROXIMATE AREA 1800 ACRES.
APPROXIMATE VOLUME 6,900,000,000 GALLONS.
DEPTH CONTOUR INTERVAL 5 FEET.
DATUM 785 FEET, MEAN SEA LEVEL.

MAP ADAPTED FROM A MAP FURNISHED BY
THE INDIANAPOLIS WATER COMPANY.

THIS MAP MAY NOT COMPLY WITH NATIONAL MAP
ACCURACY STANDARDS.

Figure 42

STATE OF INDIANA
INDIANA DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

MAP OF
GEIST RESERVOIR
SHOWING DEPTH CONTOURS
MARION AND HAMILTON COUNTY
1959

SCALE
800 0 800 1600 2400 3200 4000 4800 5600 Ft.

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   2a. p. 616-619.
   2b. p. 609.

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   3a. p. 63-65.
   3b. p. 59.
   3c. p. 85.
   3d. p. 88.
   3e. p. 79-80.

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   5b. p. 347.
   5c. p. 344.
   5d. p. 272.
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11b. p. 41.

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